ALLIS-CHALMERS Electrical REVIEW

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ALLIS-CHALMERS
Electrical REVIEW

THE COVER

STABILIZING FIELD WINDING of a coil for the C Stellarator — the research device designed to produce controlled thermonuclear fusion reactions. One of a pair being built, the twisted helical winding will be used to carry in excess of 44,000 amperes of pulsed dc at 750 volts and is insulated to withstand 10,000 volts to ground. The winding twists the magnetic field to increase the effectiveness of the magnetic bottle, enabling higher plasma temperatures in the reaction chamber.

Allis-Chalmers Staff Photo by Michael Durante

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CONTENTS

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LOW-COST Environmental Survey for a Nuclear Facility

SAMPLE COUNTING instrumentation handles the environmental counting. The counter receives pulses from the radiation detector, amplifies and counts them. Samples must be corrected for such factors as self-absorption, geometry and energy of emission.

by G. J. WALKE
Nuclear Power Dept.
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Increasing significance of atomic energy in the power-producing field has brought increased attention to radiation control.

PRIOR TO THE CONSTRUCTION of an atomic energy facility an environmental study is carried on to measure the levels of the naturally occurring radioactivity in the area. These studies are then continued after the facility goes critical, to determine if there is any change.

Basic environmental studies, until recently, have tended to be costly, especially in the area of dramatic frills in procedures and analysis. A novel method was used in establishing norms in the Greendale, Wis., area to provide adequate data at minimum cost.

Survey indicates degree of natural radioactivity

Covering the pre-operational phase of the environmental survey, the program described was initiated one year before the reactor went into operation. Once the facility went into full scale operation, the survey was to be reevaluated, altered if necessary, and then put on a permanent, continuing basis.

The main technical reason for the survey was that the amounts of naturally occurring radiation had not been measured in the area before. If an assessment were to be made of the effect of the facility's operations on its environment, the levels prior to the commencement of operations would have to be known.

Once the level of the naturally occurring radioactivity was known and the facility went into operation, the environmental survey would serve as a final check on control procedures. The data collected from the survey would be carefully recorded and stored. In addition, all the samples collected would be carefully preserved. The samples and data would be very valuable in the future, for they would provide tangible evidence in the event the facility was called upon to prove it had added no activity to the environment.

The importance of good community relations was given careful consideration from the inception of the project. The nuclear power industry was associated in the public mind with atomic bombs and therefore with danger. The environmental survey program was one method of demonstrating to the public the precautions taken for its safety. The fact that a natural background of radioactivity existed at all, helped to bring some of the features concerning radiation and radioactive materials, which were previously not generally known, into better focus in the public mind.

Program includes variety of tests

Elements monitored in the survey are water, soil, vegetation and air. Surface water is collected quarterly from Lake Michigan and an inland lake nearby, while tap (well) water is collected monthly. Both types of water samples are then counted for alpha and beta activity. Grass and soil samples are collected semi-annually from a number of points surrounding the site. After appropriate processing the grass and soil samples are also counted for alpha and beta activity.

Air is monitored by two methods. First, a number of fallout jars are located at various points surrounding the site and on the roof of the nuclear power laboratory.

Precipitation and dust samples are collected in the fallout jars for one month. These samples are evaporated to dryness and the residue is counted for alpha and beta activity.

Secondly, a continuous air sample is taken on the roof of the nuclear power laboratory. Air is continuously drawn through an aerosol membrane filter at a known rate for a period of one week. The air filters are counted for alpha and beta activity. Figure 1 shows the exact location of each sampling point. It will be noted that the sampling points lie roughly on two concentric circles whose center is the Greendale facility.

Once the gross counts are completed, the raw counting data is normalized and recorded. The results are then checked and any sample which is above the maximum permissible concentration (MPC)* for unidentified radionuclides in air or water is analyzed for specific nuclides. The grass and soil samples are analyzed if they are found to exceed an arbitrary level.

Remaining samples are carefully stored. Since most of the radionuclides of greatest concern have relatively long half lives, the samples may be analyzed at some future date with little error, if the need arises. Up to the present time, no environmental sample has been found that exceeded the MPC.

Samples are tested in several ways

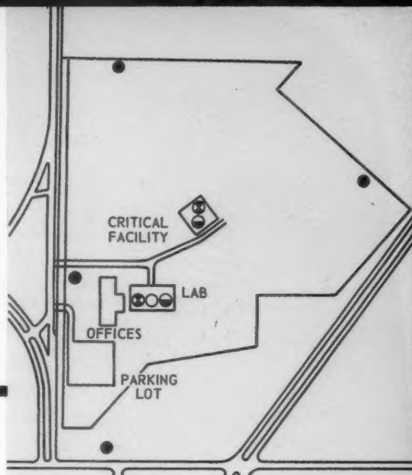
The method of collecting and preparing the various samples for counting is straightforward and requires only the simplest equipment.

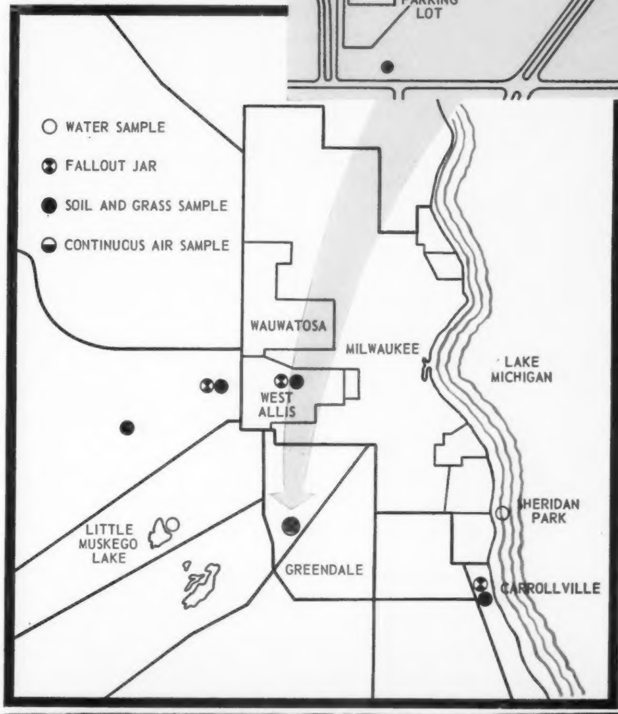
Water samples are collected in one gallon containers. Their preparation for counting consists of first reducing four liters of water collected to approximately 50 milliliters by evaporation on a hot plate. The last 50 milliliters of the water sample are then evaporated to dryness in a one-inch diameter, one-fourth-inch high, stainless steel planchet under an infrared heat lamp. The precipitation and dust samples collected in the fallout jars (six-inch diameter battery jars) are prepared for counting in exactly the same manner as the water samples.

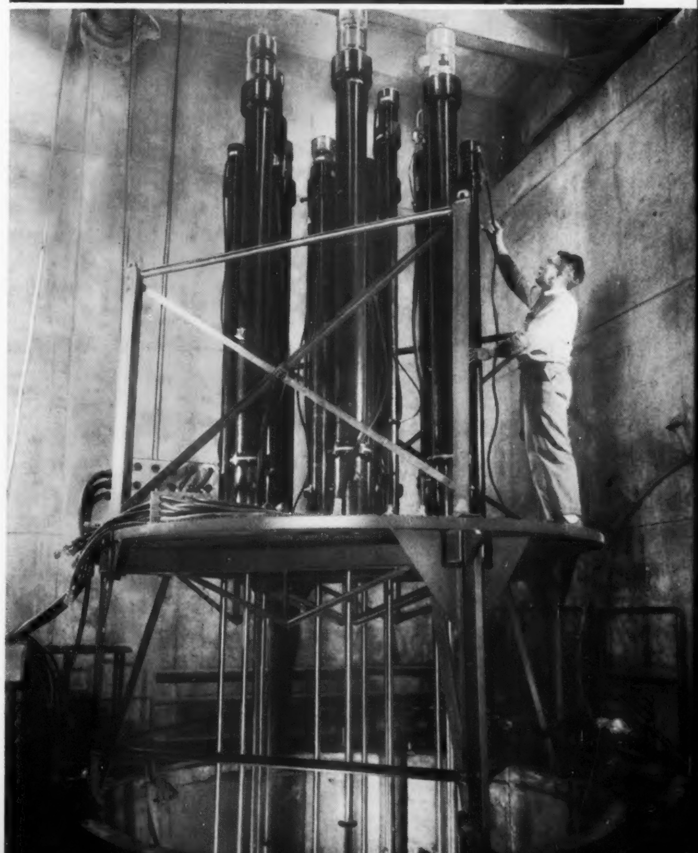
Grass samples are collected by cutting enough grass to fill a twenty-pound bag. Care is taken that only cultivated grass is collected at each sampling point so that data obtained from different points would be directly comparable. Preparation of the grass for counting consists of first washing it to remove dirt and fallout dust collected on the blades. Then the grass is drained in screen trays and placed in a drying oven at 110 F for 16 hours. Next the grass is placed in ceramic crucibles and ashed at 1000

* The MPC for a radionuclide is defined by the National Committee on Radiation Protection as the maximum average concentration of a radioactive element which may be permitted in air or water without eventually resulting in excessive accumulation of material in the body if the air or water were continuously consumed by humans.

AMOUNT of naturally occurring radio-activity is determined through the gathering and analyzing of air, water, soil and grass specimens on a continuing basis. Actual environmental counting is done by automatic sample counters. Sampling points are located in area resembling two concentric circles with the Greendale site in the center. **(FIGURE 1)**







IMPORTANT DATA essential for the design of a large controlled recirculation boiling reactor with nuclear superheater will be obtained by experiments with this water-moderated, unpressurized, heterogeneous-type reactor at the Greendale Laboratory. Technician checks electrical connections for the control rod drive mechanism.

TABLE I

Typical Results from the Environmental Survey Program of the Greendale, Wis., Laboratories

Sample Type	Total Activity as 1.36 Mev Equivalent Betas	Total Activity as 5.3 Mev Equivalent Alphas
Ashed Grass	400 $\mu\mu c$*/gm	20 $\mu\mu c$/gm
Soil	30 $\mu\mu c$/gm	50 $\mu\mu c$/gm
Tap Water	10 $\mu\mu c$/liter	10 $\mu\mu c$/liter
Lake Water	15 $\mu\mu c$/liter	3 $\mu\mu c$/liter
Total Fallout (Precipitation plus Dust)	6 $\mu\mu c/cm^2$/month	0.01 $\mu\mu c/cm^2$/month
Atmospheric Air	1.3 $\mu\mu c/m^3$	0.003 $\mu\mu c/m^3$

* 1 $\mu\mu c = 10^{-12}$. Curie = 2.22 disintegrations/min.

F. The ashed grass is packed in stainless steel planchets and is ready for counting.

Soil samples are collected from the same spots as the grass samples. A four-inch square piece of sod is removed and a half-pint jar is filled with the soil from the top few inches. The soil is first pulverized and strained, then it is dried at 110 F for 16 hours. After packing into the one-inch stainless steel planchets, it is ready for counting.

The air filters, thin plastic membranes which are highly efficient for retaining 0.1 micron aerosol particles, need no preparation for counting. However, they are stored for 48 hours to allow the radon-thoron daughter products to decay.

Counting is done by special equipment

All of the environmental counting is done on an automatic sample counting set-up, Figure 2, consisting of a pulse counter, a sample changer and an elapsed time printer.

Receiving the pulses from the radiation detector, the counter amplifies and then counts them. The preset count feature of the pulse counter permits the sample to be counted for a predetermined number of counts, then the sample changer turntable is automatically rotated for the next sample to be counted. This permits the samples to be counted continuously and unattended. The sample changer has 25 sample wells which hold the standard one-inch diameter stainless steel planchets. The time required to reach a predetermined count is printed on a paper tape by the elapsed time printer. This tape serves as a permanent record of the counting.

A scintillation detector and G-M tube are used as the radiation detectors with the pulse counter. Beta activity is counted by a neon-halogen G-M counter tube with an end mica window.

Alpha activity is counted by a scintillation detector. This detector employs a silver activated zinc sulphide fluorescent screen which stops incident alpha particles and yields a flash of light quanta. A very sensitive photo-multiplier tube then detects the scintillation of light and by electron multiplication amplifies the photo-electron charge initially produced to provide a pulse to actuate the pulse counter.

When the sample has been counted for a long enough time to reduce the statistical error to acceptable limits, the counting rate may be determined readily from the data on the printed tapes. This raw counting rate must be corrected so that the true activity, expressed as curies per unit volume or unit weight, may be obtained for each sample. Samples as thick as the ones counted for the environmental survey program should be corrected for background, self-absorption, self-scattering, back scattering, counting geometry, energy of emission and absorption in air and the detector window.

Since the samples contain an unknown mixture of fission products, the corrections are impossible to make without an extensive chemical analysis. To circumvent this difficulty, a method for correcting activity measurements has been developed by various investigators.

While this type of analysis gives little information as to the identity of the radioactive nuclides in the sample, the total activity measurements are valuable when large numbers of samples are involved. They provide a rapid and simple means of comparing activity levels in different samples and indicate which samples should be analyzed for specific nuclides.

Beta activity is analyzed and recorded

One means of determining total beta activity consists of measuring for one standard nuclide the correction factors necessary to convert counting rates to total activity. These correction factors are then applied to the counting rates of beta particles emitted from unknown samples.

Accuracy of the values thus obtained depends mainly on how well the beta particle energies of the standard nuclide agree with those from the mixtures of nuclides in the unknown samples.

In the Greendale environmental survey work, the common radioactive contaminants were natural uranium, potassium-40 and mixed fission products from bomb debris. Potassium-40 which emits a 1.36 mev beta particle was chosen as the beta standard. This beta particle has approximately the same energy as the average energy of beta particles from a mixture of new fission products.

Corrections curve for potassium-40 was obtained by first counting a number of planchets containing various amounts of potassium chloride. The specific activity of potassium chloride, in curies per gram, from potassium-40 was next calculated. By dividing the counting rate from each planchet of potassium chloride by the number of curies for that weight of potassium chloride, a quantity was obtained whose units are counts per minute per curie.

Plot of this quantity versus the weight of each sample of potassium chloride gives the correction curve for potas-

sium-40. In applying this correction to the counting of samples of mixed radioactive nuclides, all that is necessary is that the counting rate of the sample be divided by the counts per minute per curie from the correction curve corresponding to the weight of the sample of unknown nuclides.

This technique was extended to alpha counting with but a few changes. A solution containing a known quantity of polonium-210 was mixed with soil or ashed grass to plot the correction curve. Polonium-210, which emits a 5.3 mev alpha particle, was chosen as the alpha standard because the energy of the alpha particles emitted is close to the average energy for alpha particles from most nuclides.

Correction of the counting rates to total activity for the air filter samples was handled by the use of standard sources. The counting rate of each air filter sample is merely divided by the counter efficiency as determined by a standard source. The alpha standard is a silver disk with a thin coating of polonium-210, while beta standard is a silver disk upon which a coating of radium D & E is planted.

Results are interpreted and program evaluated

When using this method of analysis to determine the activity of an unknown sample, the interpretation of the resulting activity is somewhat as follows: The sample had an activity such that if only beta particles of the same energies as those emitted by potassium-40 (about 1.36 mev) were emitted by the sample, then this would be the true activity. Thus, the value of activity per unit weight or unit volume calculated in this manner gives only the potassium-40 concentration that would have produced the observed activity in the unknown sample.

Activities of unknown samples should then be reported as "1.36 mev beta equivalent" to avoid being misleading. A similar interpretation is applied to the use of the standard alpha nuclide.

Table I shows typical results from the environmental samples as collected and assayed by the Greendale facility. They agree closely with data published by the health physics departments of the Armour Research Foundation and the Argonne National Laboratory. Data from Sedlet show that the absolute accuracy of this type of activity determination is plus or minus 50 percent. In cases where the sample is relatively thin, the accuracy is increased to plus or minus 20 percent. This type of accuracy is more than adequate for the purposes of the environmental survey program.

Information obtained from this type of environmental survey program has been shown to be accurate and relatively inexpensive. The system of using fallout jars, air filtering, water, soil and grass samples is considered the best compromise for a low-cost, reliable, and sensitive measurement of environmental radioactivity fluctuations. In addition, this system has the highly desirable feature of having overlapping measurements for checking purposes.

PRECIPITATION and dust samples are collected in fallout jars located at sites surrounding the facility. Specimens are evaporated and the residue is counted for alpha and beta activity.

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Metal-Enclosed SAFETY For Interrupting Switch

ADVANTAGES of metal-enclosed drawout switchgear are now available for load interrupting switch. Shutters cover live bus when switch is withdrawn. Fuses are withdrawn with the switch and may be replaced with safety. Enclosure matches metal-enclosed switchgear.

by W. H. LANE
Switchgear Department
Allis-Chalmers Mfg. Co.

Distribution voltage interrupting switch solves safety and flexibility problems with switchgear-type designs.

IN RECENT YEARS air interrupter switches, fused and unfused, have found increasing application in industrial and commercial power systems. They have been applied as feeders in power switching centers and as high voltage switches in load-center substations and distribution centers.

Previously, the high voltage switch has been available only permanently mounted in a metal-enclosed cubicle and all maintenance and servicing required de-energizing of the power circuits before any work could be done. Generally, power fuses had to be located on the load side of the switch so that they could be changed without the necessity of de-energizing the source.

To solve the distribution switching and fusing problems in the 15-kv and lower class, a metal-clad drawout interrupter switch unit was developed to make the fused air interrupter switch adaptable to as many industrial applications as possible. The convenience and reliability of the new metal-enclosed design make the drawout switch attractive for utility use in conjunction with line-ups of conventional metal-clad air-magnetic circuit breakers.

New safety gained

Applying the well-established principles of metal-clad switchgear to the design of a drawout switch resulted in greatly improved safety for operating personnel. With the switch in the connected position in the stationary cubicle, as shown in Figure 1, all of the live conductors are fully enclosed in a grounded steel housing. The drawout element is locked into the cubicle and cannot be unlocked for withdrawal when the switch is in the closed position. Conversely, interlocking prevents the switch from going into the cubicle if in the closed position. Also access to the fuse compartment of the drawout switch is not possible if the switch is within the stationary cubicle.

While the switch is being operated, maximum operator safety is provided by the quick-make, quick-break mechanism on the switch operator. By the use of an over-center linkage and energy storage the switch blades are always closed or opened at a uniform high speed. This speed is completely independent of the speed at which the operator moves the switch handle. The quick-make device guarantees that the switch will close and remain closed, even when closed against a full-rated fault.

Drawout metal-clad construction provides complete safety to personnel during the interval when fuses must be changed. When the switch is withdrawn, complete isolation of the switch cubicle from the live circuits is automatic. An insulated shutter closes off the openings between the switch compartment and the stationary high voltage terminals. Accidental injury is further prevented by a safety lock on the shutter which prevents manual operation of the shutter linkage.

Application flexibility increased

Development of the drawout load-break switch has removed one of the serious limitations which is frequently encountered when applying stationary fused load-break switching equipment.

When the fuse mountings are permanently in the high voltage circuit, it is necessary to provide for the servicing of these fuses in one of two ways. Hot line tools may be used to change the fuses "hot," or the equipment must be so constructed that the fuses become de-energized when the load-break switch is open.

Common practice for many industrial plants has been to place the fuses on the load side of the switch, leaving the fuses "dead" when the switch is open. The drawout load-break switch, on the other hand, has the fuses on the source side of the switch for all circuit applications. Greater circuit and equipment protection is thereby possible because the fuses provide short-circuit protection for the switch as well as the circuit. A fault in the switch will be cleared by the associated fuses without the need for operation of backup breakers which may be supplying circuits other than the one in trouble, as shown in Figure 2.

Standard arrangements available provide for the application of the drawout fused switch as a single unit, as a load-break switch for a unit substation, in complete factory assembled line-ups, and as feeder units in line-ups of high voltage metal-clad air-magnetic circuit breaker switchgear.

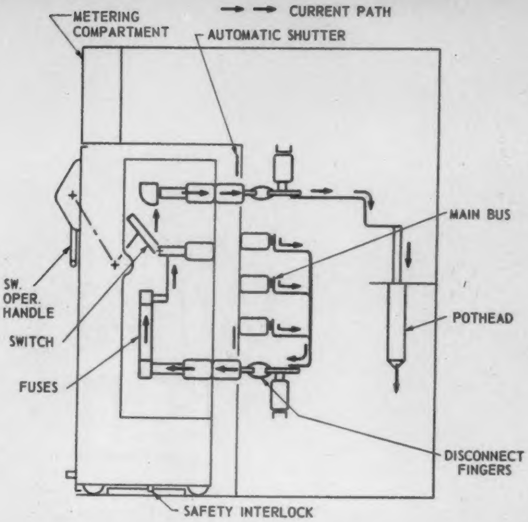
All types of connections may readily be made as required: single feed, loop feed, throats to power transformers, or bus duct connections. When used with other switchgear, the drawout switch equipment may be placed at any point in the group line-up. Outdoor requirements are met by providing standard metal-enclosed construction with a protected aisle for maintenance and servicing.

Service continues during maintenance

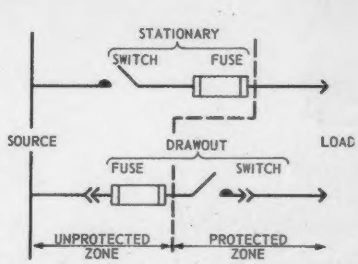
Switch withdrawal is rapidly accomplished and the complete drawout element can be quickly serviced without any danger from live conductors. When drawn out, the switch is fully accessible from all sides.

Where service interruptions must be kept to a minimum, regular maintenance may be performed by using a spare switch. The switch to be serviced may be removed and the spare inserted to restore the circuit while inspection and servicing are completed. In this way, one spare drawout switch can be used for several different locations within a plant without the need for costly duplication of facilities and throw-over arrangements at each switching location.

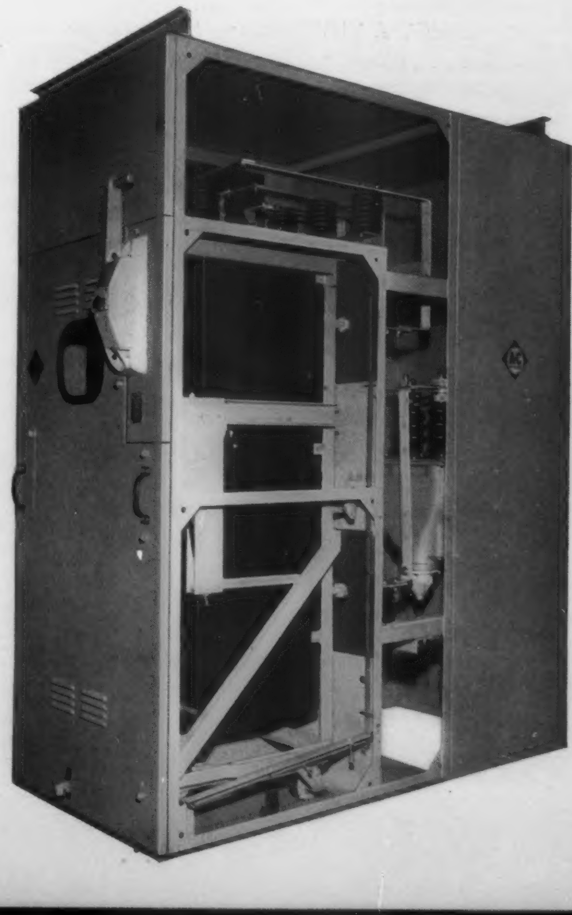
The metal-enclosed switchgear design for a distribution voltage interrupting switch will open up new economy, flexibility and safety for those planning new systems or modernizing older systems. The new type load-break switches may be used either in switchgear line-ups or as individual units in the primary of substation transformers to solve many industrial and utility switching problems.



SAFETY INTERLOCKS protect disconnect fingers by preventing the withdrawal or replacement of the switch when the switch is in the closed position. Fuses are on the source side of the switch. **(FIGURE 1)**



FUSES protect the switch as well as the load and may be replaced without disturbing the other loads on the system. **(FIGURE 2)**



SECTIONALIZED CUBICLE separates high voltage bus work from switch and metering compartments. Live buses to other cubicles in line-up are completely isolated when switch is removed. **(FIGURE 3)**

Wk² ...WHAT IS IT?

by **G. R. BROOKS**
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Motor-Generator Dept.
Allis-Chalmers Mfg. Co.

A non-technical explanation of the technicalities of the Wk^2 problem in motor starting.

Wk^2 IS NOT A TIGER that we have to approach with caution . . . downwind . . . and protected by plenty of engineers well armed with slide rules. Or if it is a tiger, it's just a paper tiger that we ought to be able to meet face to face without trepidation . . .

It's only been comparatively recently that we have seriously associated Wk^2 with motor starting. Why, then, has it suddenly become a problem? What is it? Why does it make a motor cost more?

In the first place, it is not something new. Wk^2 is merely the agreed-upon term we use to describe the flywheel affect of the rotating elements in a piece of equipment. All of us know what a flywheel is. Most of us know what it's for.

The "W" in the term Wk^2 is the weight of the flywheel. The "k" is the radius at which the weight is considered to be concentrated — as if it were a ring instead of a disk — and is called the radius of gyration.

This Wk^2 term is not restricted to apply only to the familiar flywheel shape. Large fans, for example, are also flywheels. This is also true of a variety of machines such as wood chippers, wood grinders, pulverizers, band saws, centrifugal compressors, etc. In fact, the Wk^2 of any rotating element can be calculated by the equipment manufacturer and supplied to the motor manufacturer for his consideration.

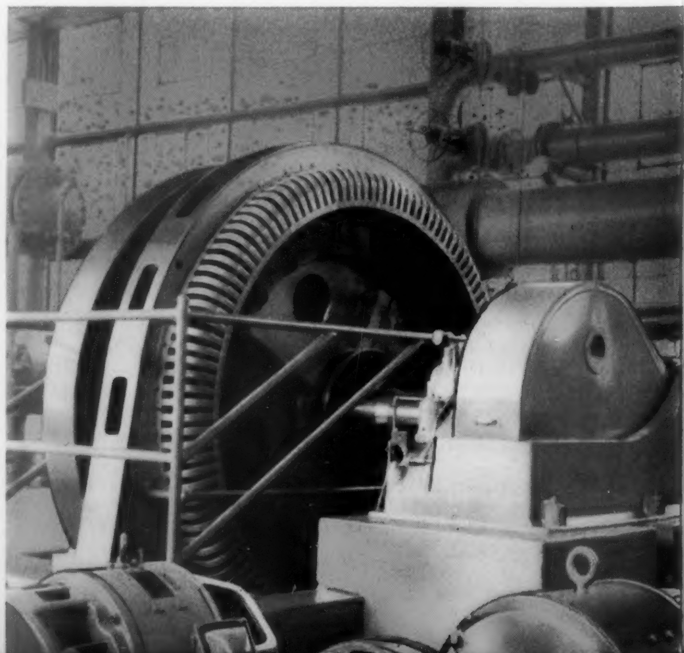
The next question, after explaining Wk^2, is why is it a problem?

Consider a flywheel for a moment. It requires a great deal of energy to accelerate a large flywheel from standstill to high speed. Conversely, it requires the same amount of energy to bring it to a stop. For this reason we say that a flywheel acts as a means to store up energy which is released when the driving force is removed.

A familiar application of this principle is the punch press. In this tool, large amounts of energy are stored in the flywheel being accelerated by a small motor over a relatively long time. Then, the energy is suddenly released in huge amounts in a fraction of a second as the die is forced against the blank metal.

To explain further, let's visualize a large flywheel at rest, coupled by means of a disengaged friction clutch to a prime mover which is running at a constant speed. Since the prime mover is already in rotation and the flywheel is at rest, engaging the clutch will cause a great deal of heat to be generated between the rotating and stationary clutch plates. As the flywheel accelerates, this condition will be progressively relieved until the speed of the flywheel reaches that of the prime mover and the clutch is driving the flywheel directly without slipping. The larger the flywheel and the higher the speed to which the flywheel is accelerated, the more heat will be generated by friction.

Without going into the laws of the physics involved, it is known that the total energy wasted in the friction clutch is the same as that required to accelerate the flywheel. Thus the prime mover must supply half of the total energy involved to the clutch and the other half is stored in the flywheel. This allows us to state that the energy wasted in the clutch is equal to the stored energy in the flywheel. This is important because the energy



stored in the flywheel can be calculated knowing only two things — its Wk^2 and its top speed. The same amount of energy appears in the clutch.

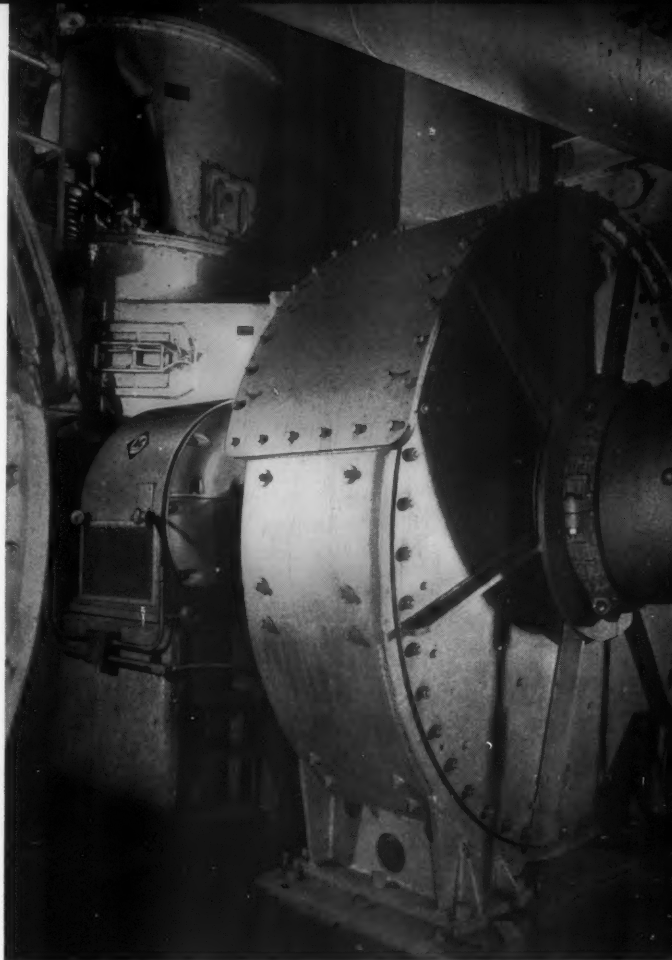
We get the same results if we say that our ac power lines represent the prime mover. An ac motor, electrically connected to the power lines through an open motor starter, represents the disengaged clutch mechanically coupled to a load machine which, in turn, represents the flywheel.

When the motor starter is closed, the motor acts as the friction clutch did, to cause the flywheel type of load to accelerate. Half of the power is stored mechanically in the flywheel and half the power is stored electrically in the motor. The portion stored in the motor appears as a heating loss in the rotor starting, squirrel-cage winding. The effect of loading during acceleration is ignored and only the flywheel effect considered.

This means that if we know the Wk^2 involved and the speed, we can calculate the stored energy of rotation . . . and that this stored energy appears as a heat loss in the rotor starting winding of the motor. The reason it makes a motor cost more is that oversized starting windings must be provided in order to handle the additional heat safely.

Danger of overheating the motor has always been a problem where large Wk^2 is involved. The reason it seems like a new problem is that fans, chippers, etc., are growing larger. As the size of steam turbine-generator units continues to increase, the associated forced and induced draft fans become larger and the Wk^2 problem is encountered more frequently.

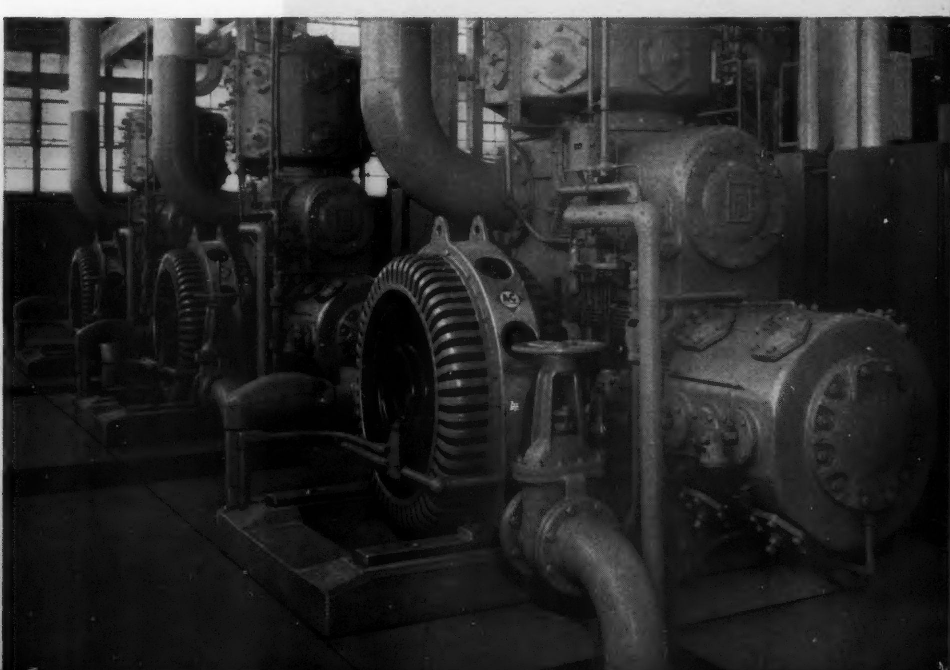
Wk^2 is relatively simple to understand, and its problems are easy to solve, but the important things to recognize are that: (1) Modern high Wk^2 loads require special motors to provide safe acceleration and (2) the number of successive starts should be restricted to prevent overheating.



HIGH Wk^2 LOADS ENCOUNTERED in industry today necessitate special motors to provide safe acceleration. This 400-hp unit is one of four induction motors driving coal mills. Oversized squirrel-cage winding is often provided in order to handle safely the additional heat developed by the high Wk^2. This modification frequently ups motor costs.

◀ **A FLYWHEEL HAS** been added to this 600-hp synchronous motor to smooth out variations in current caused by a reciprocating compressor load. Because of the flywheel, heavier squirrel-cage winding is necessary.

LOOKS CAN BE deceiving. This line-up of large reciprocating compressors is driven by 350-hp synchronous motors. While the compressors appear to be very large, they have normal Wk^2 and standard motors have been applied.



Wk^2 ...AT WHAT SPEED?

by **R. C. MOORE**
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Accelerating or decelerating high Wk^2 loads through speed changers sometimes confuses the selection of drive motors. Referring the speed to the motor shaft simplifies the problem.

WHEN SPEED CHANGERS are used, calculations to determine factors involving Wk^2, such as accelerating time and motor energy losses, may be more easily made when all Wk^2 values are referred to the shaft of the motor where torque is developed.

Among high inertia loads that often have some type of speed changer are centrifugal compressors, blowers, pulverizers and log chippers.

Except for windage and friction losses, a rotating body having a given value of Wk^2 makes no torque or horsepower demands of the driving motor at a steady running speed. Should a change in speed occur, the inertia effect of the rotating parts resists this change. During starting from rest to full speed, the resistance of the inertia to speed changes must be overcome by motor torque in accordance with the equation:

$$T = J\,a \qquad (1)$$

where T = motor torque in lb-ft (pounds-feet).
J = polar moment of inertia of load and equals Wk^2/g.
a = acceleration in radians per second per second.

The time for a motor to accelerate a given Wk^2 load from rest to full speed may be determined from Eq. (1). Substitution of equivalent quantities for J and a in the equation may be made as follows:

$$T = \frac{Wk^2}{g} \times \frac{2\pi \text{ rpm}}{60\,t} = \frac{Wk^2 \text{ rpm}}{308\,t}$$

where Wk^2 = inertia in lb-ft^2.
g = gravity constant, 32.2.
W = weight of rotating parts in pounds.
k = radius of gyration in feet.

or

$$t = \frac{Wk^2 \text{ rpm}}{308\,T} \text{ seconds} \qquad (2)$$

where t is the time in seconds to accelerate an inertia Wk^2 from rest to speed in rpm with motor torque T applied. Since T and rpm are motor values in Eq. (2), Wk^2 values must all be expressed at the motor speed. Hence a load inertia driven through a speed changer may not be arithmetically added to the motor Wk^2. However, the actual load inertia may be replaced by an equivalent Wk^2 operating at the motor shaft speed. The motor and equivalent load Wk^2 may then be arithmetically added so that Eq. (2) may be directly applied.

Losses depend on Wk^2 accelerated

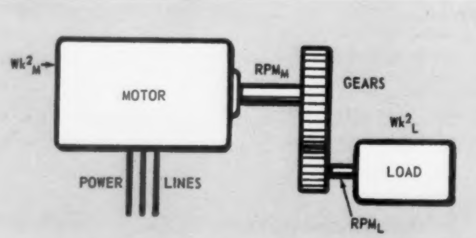
In accelerating the load Wk^2 to full speed, losses are developed in the stator and rotor windings of synchronous and induction motors. The losses are produced by currents flowing through the resistances of the windings and are referred to as I^2R losses.

A given motor requires a longer time to accelerate a large Wk^2 than a small Wk^2 in accordance with Eq. (2), and the energy losses in the motor windings, I^2R times t, are higher. When applying motors, therefore, consideration must be given not only to normal load horsepower requirements but also to the load inertia which the motor must accelerate to operating speed. A guide for applying polyphase squirrel-cage induction motors requiring starting inertia Wk^2 loads may be obtained from applicable NEMA Standards.

Standards give load Wk^2

The standards list Wk^2 values of loads for which induction motors of more than 200 hp and of various speed ranges may be applied. The listed values apply to direct-connected loads such as fans, where the torque varies as the square of the speed and equals 100 percent of full-load torque at rated speed. Thus a 40 C rise cage-type polyphase induction motor of listed horsepower rating and speed may be allowed two successive starts with the motor initially at room temperature, or one start with the motor initially not exceeding rated temperature. The standards may be consulted for other details relating to additional starts.

Since Wk^2 values listed in the standards are for loads which are driven at the same speed as the connected motor, inertia loads which may be geared or belted to the motor must be expressed as an equivalent Wk^2 operating at the motor shaft speed.



Motor drives load through speed changer. (FIGURE 1)

Kinetic energy determines equivalent Wk^2

The load shown in Figure 1 is driven through gears or belts at a speed RPM_L, which may be higher or lower than the speed of the driving motor. Kinetic energy, K. E., stored in the load inertia may be expressed by the following equation:

$$K.\ E. = \tfrac{1}{2} J_L \omega_L^2, \text{ foot-pounds} \qquad (3)$$

where the subscript $_L$ refers to the load. The polar moment of inertia J_L may be obtained from Eq. (1), and

ω_L = angular velocity of the load rotating parts, radians per second.
$= 2\pi\ rpm_L/60$.

Substituting for J_L and ω_L, Eq. (3) may be expressed as:

$$K.\ E. = 1.70\ Wk^2\ (RPM)^2\ 10^{-4} \text{ foot-pounds} \quad (4)$$

Electrical engineers may prefer to express energy stored in rotating parts in kilowatt-seconds. Such an expression may be obtained by recalling that horsepower is work done at the rate of 550 foot-pounds per second and kilowatts equal 0.746 times horsepower. Thus K. E. stored in the rotating parts may be expressed as:

$$K.\ E. = 2.31\ Wk^2\ (RPM)^2\ 10^{-7} \text{ kilowatt-seconds} \qquad (5)$$

Load Wk^2 referred to motor shaft speed

At full speed the stored energy in the rotating load inertia geared to the motor may be computed from Eq. (5), since actual load inertia Wk^2 and load speed RPM_L may be presumed known. The same kinetic energy may be stored in an equivalent load inertia Wk^2_{LM} running at the motor speed RPM_M. Thus,

$$K.\ E. = 2.31\ Wk^2_L\ (RPM_L)^2\ 10^{-7} = 2.31\ Wk^2_{LM}\ (RPM_M)^2\ 10^{-7}$$

where Wk^2_{LM} is an equivalent load inertia running at the speed of the motor shaft.

From the equality expressed in the equation,

$$Wk^2_{LM} = Wk^2_L\ (RPM_L^2/RPM_M) \qquad (6)$$

Equation (6) provides a method of obtaining the equivalent inertia of the load, Wk^2_{LM}, which may be then assumed directly coupled to the motor shaft and running at the motor speed, RPM_M. An example may serve to illustrate the use of Eq. (6).

A 1000-hp, 1180-rpm, squirrel-cage induction motor is geared to a compressor having a Wk^2 of 1000 lb-ft^2 running at 3600 rpm. The equivalent Wk^2 of the compressor at 1180 rpm is, therefore, from Eq. (6),

$$Wk^2_{LM} = 1000 \left(\frac{3600}{1180}\right)^2 = 9300 \text{ lb-ft}^2$$

The load Wk^2_{LM} may be arithmetically added to the motor Wk^2 to obtain the total inertia of the motor and load. Such inertias as coupling halves and gears on the high speed side may be similarly expressed in equivalent terms at the motor shaft speed.

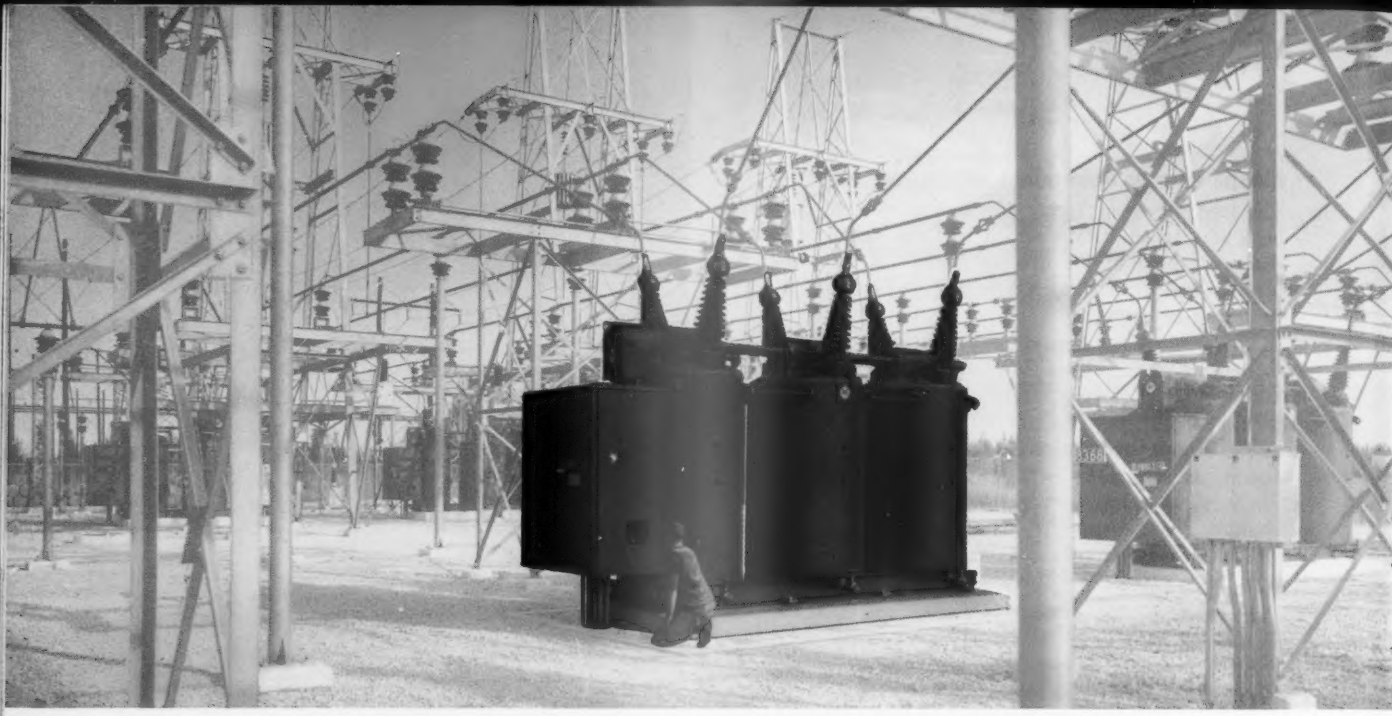
Expressing load Wk^2, running at a higher or lower speed than the motor, in terms of equivalent Wk^2 values at the motor shaft speed has many helpful applications. To determine starting time or dynamic-braking time, Eq. (2) may be directly applied. Belted drives may be computed in the same manner as the geared drives. Other applications useful to engineers include determination of motor rotor energy loss during starting and dynamic braking as well as problems related to speed variations.

ACCELERATING TIME and motor energy losses can be quickly computed when inertia values are referred to the motor shaft where torque is developed. This 200-hp synchronous motor is installed in a rubber mill.

REFERENCES

1. NEMA Standards Publication "Motors and Generators," MG 1-1959, Part 14, National Electrical Manufacturers Association, 155 East 44 Street, New York 17, New York.
2. "Starting and Control of Polyphase Squirrel-Cage Induction Motors," H. M. Norman, AIEE *Transactions*, Vol. XLV, 1926.

CHANGE IN MOTOR SPEEDS results in an increased inertia resistance which must be overcome by motor torque. These totally enclosed, explosion-proof motors drive rotary compressors in an industrial application.



OIL CIRCUIT BREAKERS are a vital part of modern power transmission systems. Typical of the larger size breakers commonly seen in outdoor substations are these 69-kv, 5000-mva units in the Southeast.

OIL FOR YOUR CIRCUIT BREAKERS

by **N. M. RUSSAK**
Boston Works
Allis-Chalmers Mfg. Co.

What is good oil?
What isn't?
How is oil tested?
Can used oil be restored?
Here are some facts about breaker oil.

THE PROTECTION OFFERED to a power system by an oil circuit breaker is vitally dependent on the quality of the oil in which the breaker operates. The oil aids in deionizing the arc by cooling it and by carrying it away from arcing contacts. The oil also serves as insulation and is selected with both these functions in mind.

Basically, oil is composed of paraffinic hydrocarbons, aromatics and naphthenic hydrocarbons. In the mineral oils, the paraffins, or paraffinic hydrocarbons, comprise the solid state of the oil, and the naphthenics, or the naphthenic hydrocarbons, make up the liquid portion of the oil. Of the three parts of oil, the most important is the aromatic, which controls the oil stability.

If oil and water are agitated, the solution is the same, but the water settles to the bottom and the oil goes to the top because there is no binder or aromatic within the solution. If the oil is emulsified by using an aromatic, the same mixture can be agitated and a new solution obtained.

An arbitrarily selected solution is shown in Figure 1. Variation of the amount of aromatic determines the stability of oil. By treating the oil with acid to remove some of the aromatic, a new solution such as shown in Figure 2 can be obtained. The process produces an insulating oil of higher chemical stability which resists oxidation. This refining process of removing some aromatic is called acid refining or solvent refining.

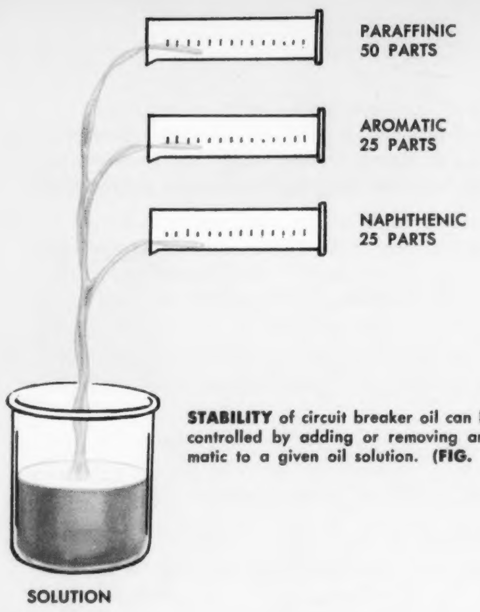
The two basic types of oil are the paraffinic crudes and the naphthenic crudes. Paraffinic crudes have high pour points and are found in the eastern part of the United States, mainly in the states of New York, Ohio, Pennsylvania. The naphthenic crudes, which have low pour points, are ordinarily found in Texas, Oklahoma, and New Mexico. Paraffinic oils are less suitable for dielectric oils than are naphthenic oils.

Inhibitors rejuvenate used oil

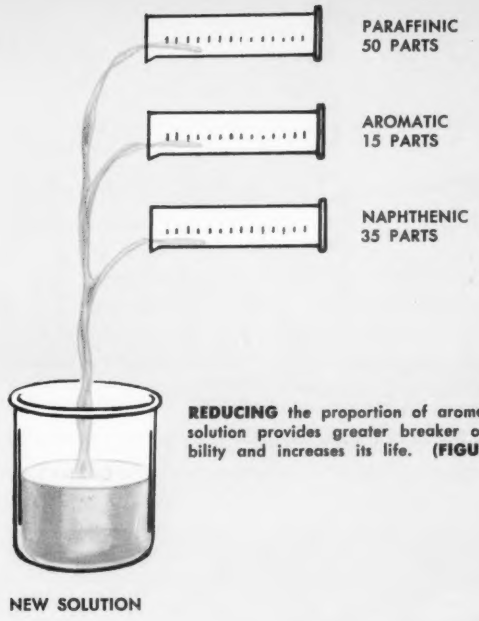
As a rule, inhibitors are not added to new oils, because new oils contain their own natural inhibitors. However, inhibitors are added to oils that have aged or deteriorated over a period of time, to restore the oil to as near its original state as possible.

The aging curve of a moderately refined oil is shown in Figure 3. Values for points *A, B, C* or *D* can be established based on experience. The index is based on changes in the dielectric strength, acidity, change of color, change in pour points or any other measure of oil quality.

The curve in Figure 4 compares an overrefined oil with a moderately refined oil. Note that the quality between points *A* and *B* is high. With overrefined oil, the point at which a major failure will occur is not certain. Because the binder, aromatic or emulsifier was removed from the oil during refining, a major failure occurred at *B*.



STABILITY of circuit breaker oil can be controlled by adding or removing aromatic to a given oil solution. **(FIG. 1)**



REDUCING the proportion of aromatic in solution provides greater breaker oil stability and increases its life. **(FIGURE 2)**

A properly refined oil curve, shown in Figure 5, fits in somewhere between the moderately refined oil and the overrefined. Breakdown does not occur until a longer period of time has elapsed. When it is noticed that the overall quality of the oil is decreasing, an inhibitor is added, giving the oil additional properties and raising the overall quality to a point slightly below the original oil.

Mineral oil consists of both carbon and hydrogen. In breaker interruption the carbon and the hydrogen separate. The amount of carbon in the oil indicates how severely the oil has been subjected to arcing. Ordinarily, mineral oil starts to break down or deteriorate at approximately 250 F. Electric arcs in interrupting devices are approximately 2000 F. The organic particles in the mineral oil begin to disintegrate at these high temperatures. Factors governing the deterioration of the oil are the volume of oil at the arc, the time of arcing and the temperature of the arc.

After an interruption has occurred in oil, carbon ash is formed. The particle size of the ash is an indication of the heat intensity of the arc interruption. Crystal carbon in the tanks is an indication that a serious interruption has occurred. Variations in the results of successive dielectric tests do not measure the moisture or the carbon content but merely indicate that something has changed. The dielectric test measures only qualitative values of the ability of the oil to withstand electric stresses.

Breaker oil tests can be divided into purchasing tests and performance tests. Purchasing tests for new oils are of no practical significance for used oil. Performance tests, primarily concerned with oil stability, are run periodically after oil has been in service to determine changes. Results of these tests indicate when filtering or replacement may be necessary.

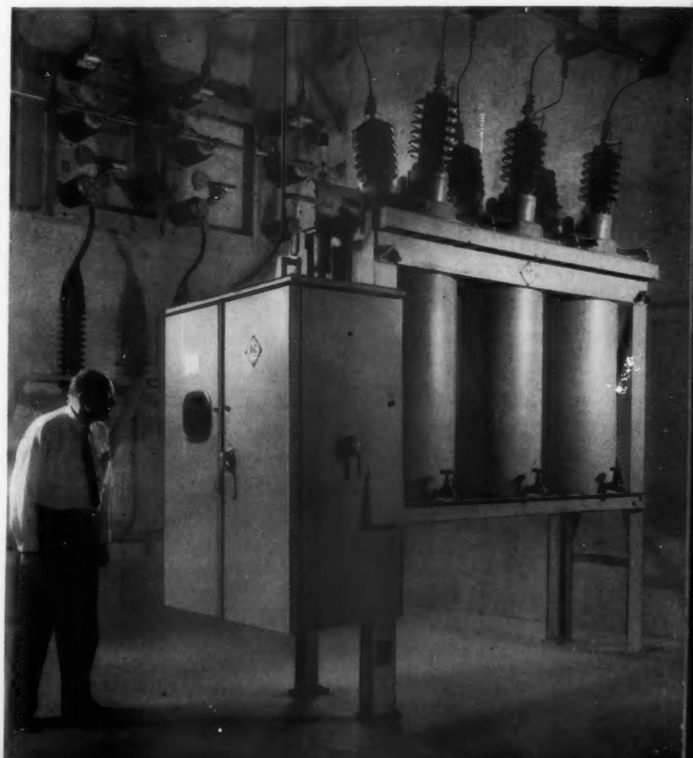
Available tests are evaluated

1. *Flash Point and Fire Point* — Since at high temperatures all oils flash, this test is not too reliable for setting up standards but is used for purchasing. Values for the flash point and fire point can be established so that used oil can be compared with these values.

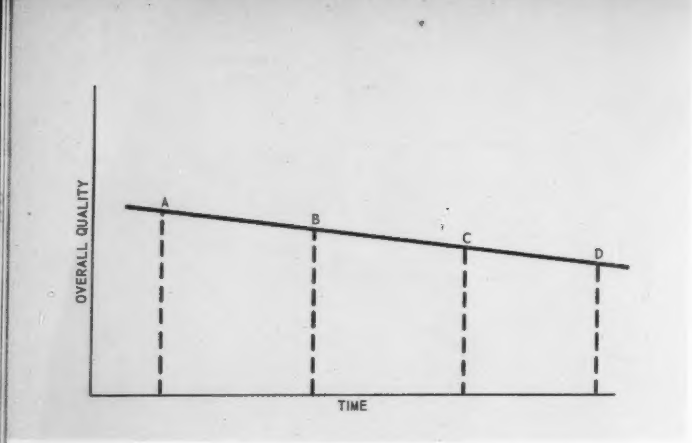
2. *Color* — Change in color has some significance as a possible indication of deterioration in the oil.

3. *Neutralization Number* — This test is important as a control for used oil. It indicates the amount of acidity present in an oil, and that sludging has occurred or can be expected.

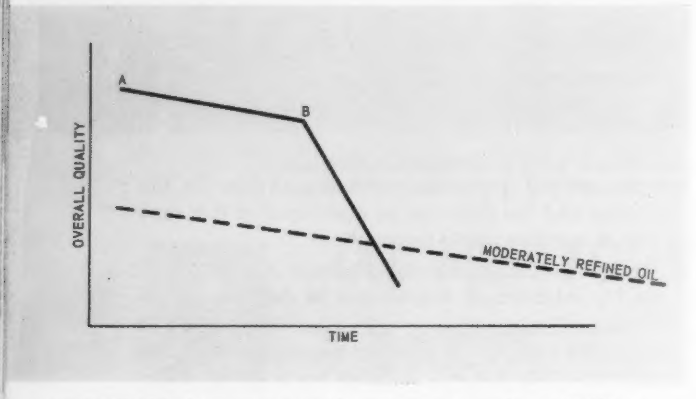
4. *Water Content* — Since no oil is bone dry, this test indicates the humidity conditions to which the oil has been subjected. During the months of July, August, and September, high humidity is prevalent in many parts of the country, and water content becomes important.



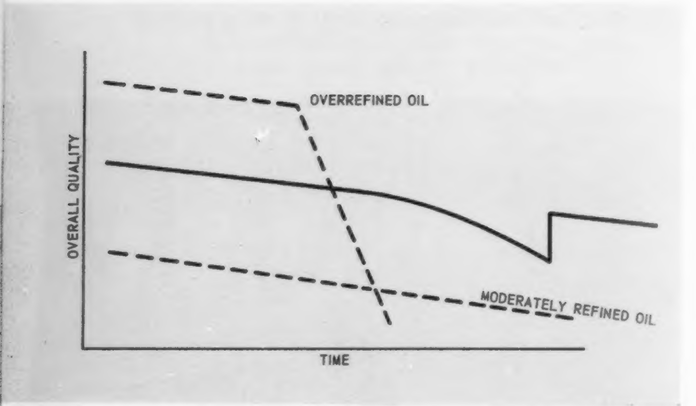
POWER CIRCUITS at Los Angeles Memorial Sports Arena are protected by two of these 1200-amp, 34.5-kv, 1500-mva interrupting capacity, frame mounted, outdoor oil circuit breakers.



EXPERIENCE has shown the rate of decline in oil quality. **(FIGURE 3)**



OVERREFINED oil has point of rapid deterioration in quality. **(FIGURE 4)**



PROPERLY REFINED OIL remains usable for a longer period. **(FIGURE 5)**

5. *Interfacial Tension*—This test is not generally needed for new oils. On used oil this test shows the extent of water content, oxidation and other contaminants in solution. The degree of sludging is indicated by this test.

6. *Dielectric Strength*—This basic field test is used to check the contaminants in the oil by determining the voltage level at which oil will break down between two metallic discs one inch in diameter and placed 0.100 inch apart (ASTM method).

7. *Power Factor*—A power factor test is not primarily used on new oil but can be used as a test on old oil that has aged.

Four additional tests are available for determining the acceptability of oil used in circuit breakers. These are:

1. *Gravity*
2. *Viscosity*
3. *Pour Point*
4. *Steam Emulsion*

If the same series of tests is performed on oil when it is new and used, the change in characteristics will indicate whether the oil is still satisfactory. Listed in Table I are the acceptable limits of oil characteristics.

The two most significant tests are acidity and dielectric strength.

Used sludged oil is always filtered and dehydrated before testing. In the field, one way to dehydrate oil is to age it for 96 hours at 150 C.

If oil is to be sent to a laboratory for testing, at least a quart will be needed. When a dielectric test of used oil is made, a separate sample of the oil is required, since the dielectric test will change the properties of the oil and render it unsuitable for other tests.

Many oil reclaimers state that they can reclaim oil from breakers and produce a better oil than the original. Although oil may be brought back to a reasonable value, it will never have the same properties as the original.

One method of refining contaminated oil in the field is to water-wash the oil. If this method is not practical, then the oil will require reprocessing at the refinery. There are four different types of reprocessing—all involving the use of clay to remove color, absorb acids, remove asphalt materials and resins, and dehydrate. For efficient refining of the oil no one clay can perform all four processes. A separate clay must be used for each separate process.

Continuous testing and a diligent oil maintenance program provide an indication of the severity of service on the individual breakers on any distribution or transmission system. A knowledge of each test and its importance will help in evaluating changes in characteristics and their effect on breaker operation.

TABLE I

Test	Recommended New Oil Values	Acceptable Used Oil Values
Flash Point	132 C-Minimum	127 C-Minimum
Fire Point	149 C-Minimum	144 C-Minimum
Neutralization Number	0.03 Mg KOH/gm Oil-Max.	1.0 Mg KOH/gm Oil-Max.
Interfacial Tension	40 Dynes/cm-Minimum	20.0 Dynes/cm-Minimum
Dielectric Strength	27.5 Kv-Minimum	22 Kv-Minimum
Power Factor	0.05 Percent-Maximum	0.1 Percent-Maximum
Carbon Content	0 Percent	0.5 Percent-Maximum

REDUCING Voltage Variation BY NEGATIVE REACTANCE

by **W. C. SEALEY**
Chief Engineer
Transformer and Regulator Depts.
Allis-Chalmers Mfg. Co.

A two-winding reactor may be used to solve your voltage fluctuation problems.

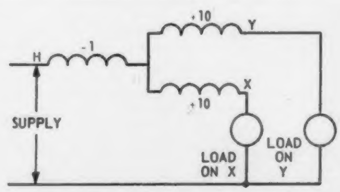
WHEN A COMPARATIVELY small or constant load and a large, rapidly changing load are both served from the same line, the resulting regulation problems can be solved by the use of negative reactance. Typical of these problems might be a metal-stamping plant where the lights dim every time a big press operates. If the lines and transformer are already installed and circuit changes would be expensive, the light flicker can be eliminated by adding negative reactance.

Negative reactance may be supplied by series capacitors, by designing negative reactance into a three-winding supply transformer, or by the use of a suitably designed two-winding inductive reactor.

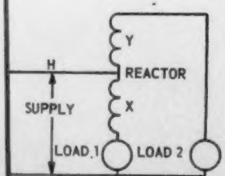
When series capacitors are used as a source of negative reactance, inductive reactance is considered positive and capacitive reactance negative. Any desired amount of negative reactance can be selected.

A limited amount of negative reactance can be built into a three-winding transformer for little or no additional cost. The equivalent circuit diagram for the three-winding transformer shown in Figure 1 is given in Figure 2. For this typical transformer the high voltage supply winding may have a reactance of -1 percent and each of the other windings may have a reactance of $+10$ percent. If the reactance of the supply line were 1 percent, the voltage on line X would not change with a change in load on line Y and vice versa.

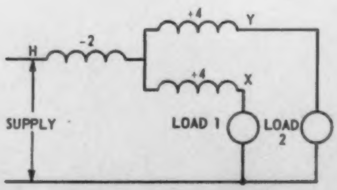
CIRCUIT of three-winding transformer. **(FIGURE 1)**



EQUIVALENT CIRCUIT of three-winding transformer with negative reactance. **(FIGURE 2)**



ACTUAL CIRCUIT of two-winding reactor. **(FIGURE 3)**



EQUIVALENT CIRCUIT of two-winding reactor with negative reactance. **(FIGURE 4)**

A third way of obtaining negative reactance is by the use of a two-winding reactor with one winding connected in series with each load. The physical connections of such a reactor are shown in Figure 3 and the equivalent circuit in Figure 4. If the reactance of the supply line were 2 percent, the voltage on X would not change due to a change in load on Y and vice versa. A reactor of this kind can be designed with any desired value of negative reactance. Positive reactance associated with each load winding has twice the numerical value of negative reactance.

If the X and Y windings of the reactor are closely coupled and we let A_X be the reactance of the X winding, A_Y the reactance of the Y winding, and A_H the reactance of the H winding in the equivalent circuit,

$$\text{then } A_H + A_X = B \qquad \text{and } A_H + A_Y = B$$

With X and Y windings connected in series, the number of turns in the circuit is doubled and the measured reactance is four times the value when only one winding is used. Consequently

$$A_X + A_Y = 4B$$

Adding the three equations

$$2A_H + 2A_X + 2A_Y = 6B$$

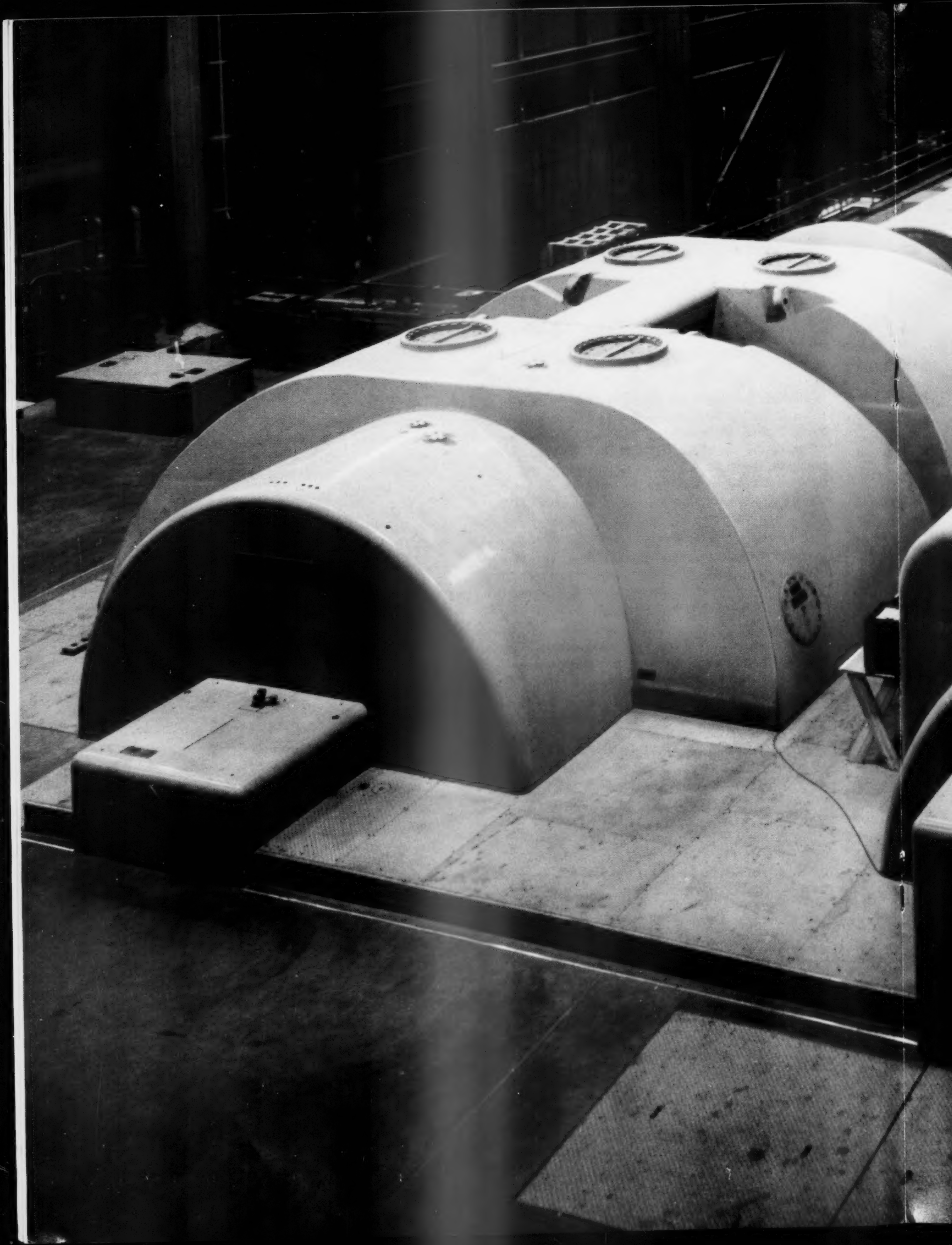
$$A_H + A_X + A_Y = 3B \text{ or}$$

$$A_Y = 2B \quad A_X = 2B \quad A_H = -B$$

That is, the value of the negative reactance associated with the H terminal has a numerical value equal to twice the positive reactance in each of the X and Y leads. Such a reactor has a center tap winding and air gaps in an iron core to produce the desired value of reactance. The current carried by each winding of the reactor is equal to one-half the line current; the maximum voltage across one winding of the reactor is the same as the voltage across the negative reactance in the equivalent circuit. Consequently, the kva parts as a reactor are equal to the negative reactance kva. Kva parts equals winding volts times winding amperes divided by 2000. This reactor introduces additional positive reactance into the load circuits, which may or may not be desirable.

Any of these three methods may be chosen to obtain negative reactance in the interest of securing more nearly constant load voltage. Each method should be considered when negative reactance is needed.

NEWEST IN TURBINE DESIGN — the 275-mw Unit 5, shown during startup at Wisconsin Electric Power Company's Oak Creek Station, is the first to use the "centerline-at-floorlevel" arrangement. Four feet of added space below the operating floor allows easy egress for extraction piping and ample space for shielded oil piping. Platforms, railings and stairs are not needed. The new concept has been applied to a shielded nuclear power unit and is adaptable for outdoor machines, where it permits gantry height to be lowered and weathertight housing to be minimized.
Allis-Chalmers Staff Photo by Michael Durante



PREDICTING REDUCED-LOAD POWER FACTOR

by **G. R. BROOKS**
Motor-Generator Dept.
Allis-Chalmers Mfg. Co.

When induction motor power factor at low loads is important, here is how to find it.

SINCE IT IS CUSTOMARY for manufacturers to report efficiency and power factor at one-half, three-quarter and full load, power factors for loads less than one-half are often desired and can be readily calculated.

All that is needed for a three-phase induction motor is the nameplate data and the one-half, three-quarter, and full-load efficiencies and power factors.

Given: A three-phase induction motor, 1500 hp, 4000 volts, 192 amps, having efficiencies and power factors as shown in Table I.

Find: Power factor and current at 18 percent load.

With this data, we now have enough information to reconstruct the load portion of the circle diagram.

Formula 1 — Percent Losses

$$\%\ \text{losses} = \left(\frac{100}{\%\ \text{Efficiency}} - 1\right) \times 100$$

Formula 2 — Motor Current, Amperes

$$\text{Amperes} = \frac{\text{Kw output} \times 1000}{\sqrt{3} \times E \times PF \times Eff.}$$

where E = line-to-line volts, three phase.
PF = power factor in per unit.
$Eff.$ = efficiency in per unit.

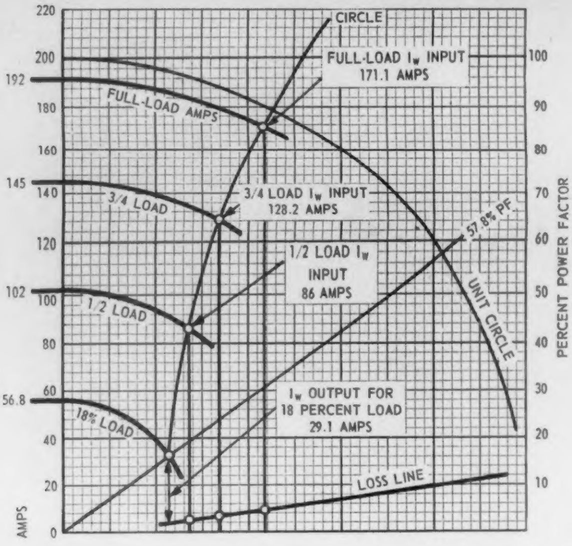
Formula 3 — Power Component of the Motor Current

$$I_w = \frac{\text{Kw} \times 1000}{\sqrt{3}\,E} \text{ Amperes}$$

where E = line-to-line volts, three phase.
Kw to correspond to the load point and proper designation.

SOLUTION:

Using a sheet of 8½ x 11-inch graph paper, as in Figure 1, choose a scale that will locate the full-load current in amperes at about the center of the shorter side of the graph.



CIRCLE DIAGRAM is reconstructed. **(FIGURE 1)**

Using the zero point as a center, three arcs through the ampere scale are swung as shown at one-half, three-quarter, and full-load amperes. Using the input I_w amperes as the vertical distance from the bottom of the graph to its proper termination at the amperes arc for the same load, the three load points are located as shown. On these same vertical lines, the three loss points are then located.

The loss line through the three loss points is drawn and a circle inscribed through the three load points as shown. This method reconstitutes the circle diagram for the motor.

$$\text{Full-load } I_w \text{ output} = \frac{\text{Output kw} \times 1000}{\sqrt{3}\,\text{E}} = \frac{1120 \times 1000}{\sqrt{3} \times 4000} = 161.7 \text{ amps}$$

18 percent load I_w output $= .18 \times 161.7 = 29.1$ amps

To obtain the 18 percent load point, the 18 percent load I_w output is laid off vertically from the loss line to the circle. Swinging an arc through 18 percent load point back to the ampere scale gives the line amperes motor current as 56.8 amps.

Power factor at any load is read off the unit circle constructed as shown: For 18 percent load = 57.8 percent.

TABLE I

Load	½	¾	1	Remarks
(A) Percent Power Factor	84.4	88.3	89.1	Given
(B) Percent Efficiency	94.1	94.7	94.5	Given
(C) Percent Losses	6.27	5.60	5.82	Formula 1
(D) Horsepower Output	750	1125	1500	Given
(E) Kw Output	560	840	1120	.746 x hp output
(F) Kw Losses	35.1	47	65.2	Kw output x 1/1 losses
(G) Kw Input	595.1	887	1185.2	Kw output + kw losses
(H) Amperes	102	145	192	Formula 2
(I) *Iw* Input	86	128.2	171.1	Formula 3
(J) *Iw* Losses	5.07	6.79	9.41	Formula 3

HOW MUCH SAFETY FACTOR?

by **R. F. SCHOOF**
Safety Services Section
Allis-Chalmers Mfg. Co.

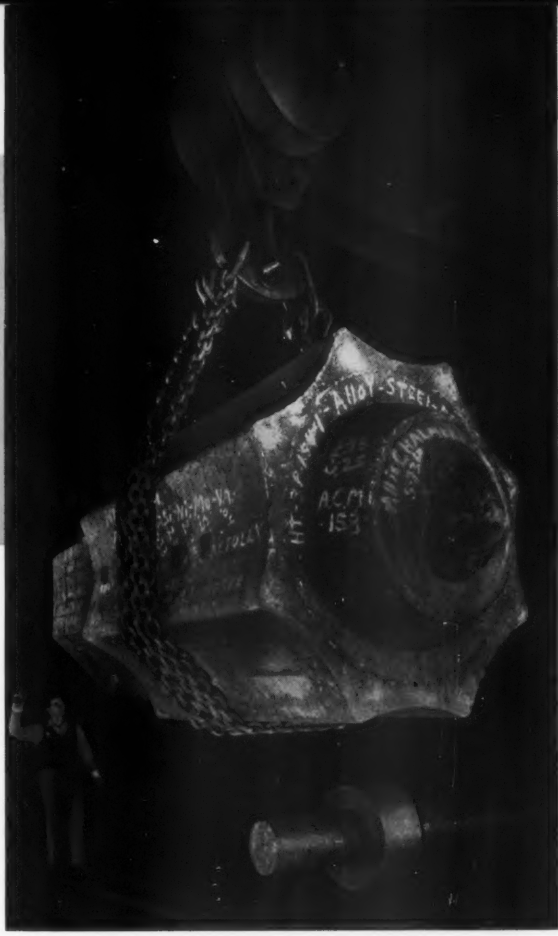
When fatigue, impact loading and stress concentrations are fully considered, design factors of 5 or 6 may mean actual safety factors of 2 or even less.

MANY SAFETY REQUIREMENTS have been established by governmental bodies, standards associations and industry groups to protect the public against injury and loss. In addition to complying with prescribed safety requirements, the designer must provide an acceptable product having a long service life. At the same time, the designer is called upon to make efficient use of materials. The choice of a proper safety factor is, therefore, a serious consideration for the engineer.

Although based in part on indeterminate factors, this choice can be guided by a number of general design approaches. The first of these approaches considers *equal tress design,* which requires that all parts are utilized at a consistent stress level and stress risers, such as sharp corners and abrupt steps in shafts, are eliminated.

A second general approach, *functional shape*, has been described as a "meditation" upon the shape that a structure would like to take. This design approach has been used to good advantage in such diverse fields as machine tools, bridge designs, modernistic building designs, and in streamlining practices. Although some of the end results may or may not possess esthetic value, these creations generally make efficient use of materials.

When the need is justified, an *individualized comprehensive stress study*, the third approach, is used. While usually costly, an intensive study of the design stresses and stress risers, possibly using strain gauges and photoelastic models, can determine with a good measure of precision the anticipated stress levels.

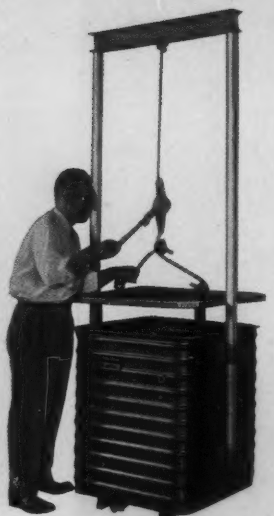


NINETY TONS of alloy steel are gently eased up in this lift in the forge shop. This unusually severe service requires lifting capacity much greater than is needed under normal operating conditions.

Ultimate use governs choice

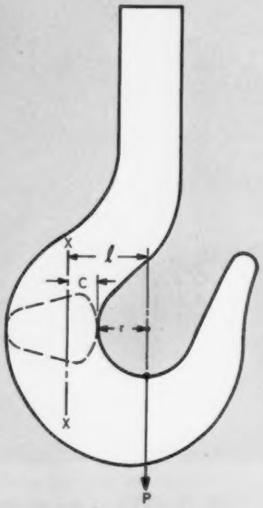
The designer will generally employ one or more of these approaches in his first analysis of a problem in building a device to perform a particular function. His design philosophy or perhaps the ultimate use or purpose of the device will govern his choice of safety factor. The safety factors required will generally be about equal for equal stress design and for functional shapes. In some cases, a smaller safety factor can be used if an individualized comprehensive stress study is made.

It is extremely important to determine at an early design stage the character of the stresses which could cause failure. Stresses which could render a material unserviceable before the end of the normal life are denoted as damaging stresses. These stresses may be at the yield point, thus causing deformation, or above the fatigue limit, subjecting the device to fatigue failure. Normal and cyclic stresses should be identified clearly. In some cases, because of complex shapes, these stresses may be difficult to determine. Even though test models may be built to resolve geometrical problems, there may be a lack of correlation between the test models or specimens and the finished product. This possible lack of correlation is particularly important when the fatigue limit is the criterion of design.



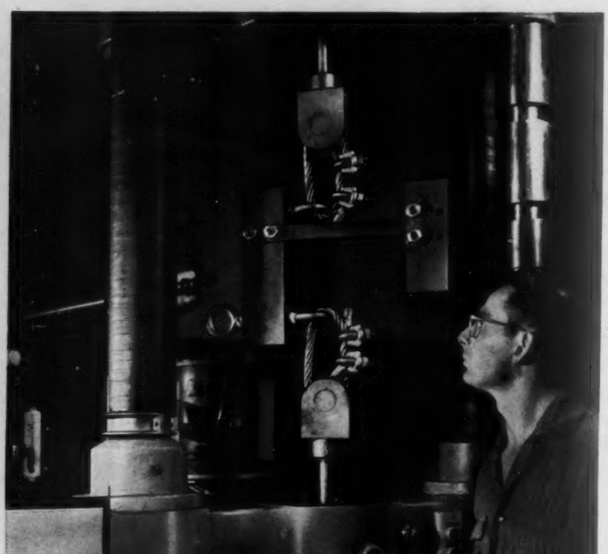
SIX-STEP ANALYSIS of safety factors was utilized for the overhead lifting arrangement to remove cover and contactor assembly of the new oil-immersed controller line. Factors considered are loss, load, stress analysis, fabrication, time and economy. **(FIGURE 1)**

FAILURE OF HITCHING devices, which can result in personal injury and property damage, is prevented by a study of the safety factors involved. A minimum safety factor of 4-5, with all stress concentrations considered in the analysis, is specified on the ultimate strength of the material.



$$S_T = \frac{P}{A} + K\frac{MC}{I}$$

S_T = max. tensile stress, psi.
P = rated capacity, lb.
A_{AA} = area of critical section, sq. in.
K = curved beam stress correction factor $\left(\text{based on ratio } \frac{L}{C}\right)$.
M = bending moment, in.-lb.
C = distance from centroid to critical fiber, in.
I = moment of inertia of critical section about the centroidal axis XX, in.^{4}
Min. Factor of Safety = 4.00 on the ultimate strength.
Min. Factor of Safety = 3.00 on the yield strength.



LABORATORY TESTS and analysis of devices designed according to theoretical calculations often result in proving the design sound and, in some cases, can result in lowering the safety factor.

The fatigue limit applying to the material, obtained either from standards or found by a special test, is still not completely determinate because of variations arising from scale factors, heat-treating differences, and surface finish variations. The fatigue limit selected should therefore be the minimum of the possible values anticipated or suitable allowance should be made in the safety factor.

Six-part analysis leads to answer

Only after the criterion of damaging stress has been established with reference to the application, and the performance capabilities of the chosen material determined, can safety factors be considered. The actual selection of a factor of safety based on a review of all the various areas of design and ultimate use can be simplified by a six-part analysis. These factors are loss, load, stress analysis, fabrication and assembly, time, and economy. In a normal application, each factor is equal to unity, and a standard factor of safety, based on either ultimate, yield or fatigue strength, is used. Special applications could affect each factor within a range of 75 percent to 200 percent. Consideration of each factor in relation to the others leads to a decision on the overall factor. Direct multiplication of the six factors is not recommended, since it tends to give unrealistically high values. A high rating of loss factor may include a sufficient allowance for such factors as fabrication and assembly, and time.

1. *Loss Factor* — what are the consequences of failure? Could failure cause loss of life, major property damage, interruption of production or service in a vital plant, or loss of user's good will?

2. *Load factor* — are the loads and therefore the anticipated stresses readily estimated with reasonable tolerance? Known impact or shock loadings which are calculable should be included in stress calculations. Suitable allowance in the safety factor should be made for complex impact loadings where approximations or estimates of possible loads must be made.

Is there multiple unit operation where loss of function of one unit transfers additional loads to remaining units? In an emergency a unit may often be required to operate up to 150 percent of normal rating.

3. *Stress Analysis Factor* — is the stress analysis straightforward and simple or are there stresses involved which, inadequately covered by theory, require approximate methods of calculation? Do vibration and torsional resonance effects warrant investigations? Some spectacular bridge and tower failures have been traced to resonance or vibration effects resulting from wind loads.

4. *Fabrication and Assembly Factor* — Materials frequently change properties while being fabricated. Residual stresses can be produced from forming, bending, punching, hammering and other work. Heat-treating problems, such as inadequate annealing, or welding and plating processes, can produce difficulties. Assembly problems may arise when an unusually high degree of skill is required to obtain maximum performance. By establishing tolerances and inspection requirements, the designer can minimize the chance of error. However, when ex-

tensive fabrication or assembly operations on a device introduce changes of indefinite character, an increase over a normal safety factor is required.

5. *Time Factor* — Devices which at the time of construction may be more than suitable for the application may not be adequate in five or ten years. In addition to the effects of wear resulting in misalignment and other difficulties, there are the problems of corrosion, decay, metallurgical changes, brittleness, and creep. Loading changes may also affect some devices. These changes are particularly prevalent in material handling equipment and factory buildings where loadings are constantly increasing. In many cases the device of today may well be expected to do tomorrow's job . . . at least for a time.

6. *Economy Factor* — Three basic considerations in economy are cost of materials, weight requirements and fabricating methods. Where materials are costly and production volume is high, overly generous safety factors are not sound and needed factors should be precisely determined. In aircraft construction, for instance, design for the lightest possible weight consistent with performance and safety requirements is the criterion and is basic for successful economic operation.

This six-step analysis of a specific application can give a definite basis for the selection of a safety factor. Where large production volumes are being contemplated, there is often a desire to reduce a factor of safety and thereby cut initial costs. Any reduction from established norms should be made only with a full understanding of all the factors involved. A major decrease in a previously accepted factor of safety can rarely be made. However, decreases of 10 to 15 percent are often feasible and safe.

For common designs, experienced designers develop standard stress levels based on accepted safety factors. These factors may be established from a variety of sources. Table I shows some standard applications. While not complete, the table indicates current practices for standard applications, but the six-part analysis should be used for unusual or special conditions.

New control shows application of analysis

A new line of oil-immersed controllers presented a problem in safety factors. One version of the device, a ground-supported model shown in Figure 1, required an overhead lifting arrangement to remove the cover and contactor assembly from the tank of oil for servicing and inspection. The arrangement consists of removable pipe supports, an I-beam and the actual lifting device. Applying the six selection factors showed that:

1. Loss factor is important because failure of the device could result in severe injury to personnel. An increase over the normal factors is required.

$$^{F}\text{Loss} = 1.25$$

2. The load factor is a fixed factor, with the weights (allowing for friction) being definitely established. No impact loading.

$$^{F}\text{Load} = 1.0$$

LARGE HYDROGEN-COOLED GENERATOR is lifted onto railroad car for shipment. Calculated design stresses for both hook and beam include factors for various fillet radii, curved beams, and holes in plates. Stress levels thus permitted are below the fatigue limit under all except severe impact loads.

3. Stress analysis is straightforward for eccentric column loading, with no vibration or cyclic loading.

$$^{F}\text{Stress} = 1.0$$

4. Fabrication and assembly factor is not a problem. The pipes and I-beam are standard structural shapes and no processing is involved other than cutting to length.

$$^{F}\text{Fab} = 0.90$$

5. Time factor is an important consideration because the device will be exposed to corrosive atmospheres and in service in excess of ten years.

$$^{F}\text{Time} = 1.25$$

6. Economy factor is not affected because aluminum is required for portability of the unit and special efforts to further reduce the weight are not required.

$$^{F}\text{Econ} = 1.0$$

The overall factor should therefore be in the range of 1.40 times a normal factor of safety (1.4 x 5.0) or 7.0 on minimum ultimate of 15,000 psi.

The devices were therefore designed using allowable loading of 2150 psi in tension for the aluminum. Calculation using this design stress showed that the pipe supports should be 2 inches in diameter and the aluminum cross-

beam a 4-inch I-beam. The lifting device utilized a 5/32-inch cable with a minimum ultimate load rating of 2800 lb. The load being lifted, allowing for possible friction, is under 400 lb, resulting in a minimum safety factor of 7 on the ultimate strength.

Material handling presents special problems

Since failure of hitching devices can produce severe personal injury and major property damage, safety factors for this equipment are extremely important. A minimum safety factor range of 4-5 is specified on the ultimate strength. Calculated design stresses include stress concentration factors (K_t) for items such as various fillet radii, curved beams, and holes in plates. The stress levels thus permitted are below the fatigue limit under all but severe impact loads.

An alloy steel bar, SAE 4340, used as part of a lift rig, is subject to fatigue failure because of its frequent loading. Since there is also moderate impact loading, a normal safety factor (for non-hitching equipment) could be 2.00 on the fatigue limit.

With reference to the six-factor analysis, the factors for this equipment are as follows:

^{F}Loss = 1.25	(Hitching equipment)
^{F}Load = 1.25 — 1.50	(Moderate impact loading)
^{F}Stress = 1.00	(Stress analysis straightforward. Fillet stress concentration factor of 1.5 included in stress calculations.)
^{F}Fab = 1.25	(Alloy steel, good quality welding and heat-treatment, rigid inspection)
^{F}Time = 1.00	(No moving parts, rating fixed)
^{F}Econ = 1.00	(Weight not critical, only one device being built)

The overall factor should therefore be approximately twice the normal factor of 2.00 or 4.00. This is based on true stress levels where stress concentration factors are included. Maximum design stresses would therefore be:

$$\frac{\text{Fatigue strength}}{4.00} = \frac{62{,}500}{4.00} = 15{,}625 \text{ psi}$$

$$\text{True safety factor} = \frac{\text{Damaging stress } (i.e., \text{ fatigue limit})}{\text{Maximum known working stress}}$$

$$= \frac{62{,}500}{15{,}625} \times (\text{impact allowance}) = \frac{62{,}500}{15{,}625}(1.5) = 2.67$$

Nominal stress calculations may be inadequate

Use of a safety factor of 5 on the ultimate, without regard to impact and fatigue loadings and stress concentration factors, would result in a true safety factor of 1.26, derived as follows:

$$\frac{110{,}000}{5} = 22{,}000 \text{ psi nominal stress}$$

$$\text{True safety factor} = \frac{\text{Damaging stress}}{\text{Maximum known working stress}}$$

$$= \frac{\text{Fatigue limit}}{\text{Nominal stress (impact load) (stress concentration factors)}}$$

If $K_t = 1.5$

$$\text{True safety factor} = \frac{62{,}500}{22{,}000\ (1.5)\ (1.5)} = 1.26$$

This value is hardly acceptable and emphasizes the need for a complete systematic analysis.

The selection of a safety factor is often governed by accepted standard design stresses or by municipal or state codes. However, many times, particularly on machine parts and devices, the selection of a safety factor is required in the early design stages. By reference and use of the six factors listed, this choice can be made using a comprehensive methodical analysis. True safety factors relating the damaging stress to the actual design stresses can be established, accurately representing the safety level intended by the designer.

TABLE I

Standard Applications of Safety Factors

Type of Loading	Safety Factor
Static loading of steels and ductile metals if elastic limit is the damaging stress	2-2.5 (on yield strength)
Static loading of cast iron	4-10 (based on ultimate strength)
Bending loads for ductile metals	4-5
Aircraft	
When materials are carefully controlled	2½-3 (on fatigue strength)
Where loads and stresses are accurately determined	2½-3 (on fatigue strength)
Where quality of workmanship is a maximum	2½-3 (on fatigue strength)
Where inspection procedures are thorough and complete	2½-3 (on fatigue strength)
Under good conditions	2½-3 (on fatigue strength)
Where there are stress risers and possible corrosive conditions	3-4
Governmental requirements for framing of public buildings:	
Wrought iron or steel	4 (based on ultimate strength)
Cast iron in tension	10
Cast iron in compression	6-8
Timber in tension or shear	6

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NON-CONDENSING automatic-extraction turbines in Midwest hospital function as reducing valves while providing dependable power. Steam is exhausted to laundering, cooking, heating and sterilizing processes.

POWER from PROCESS STEAM

by **W. C. FRAZIER**
Steam Turbine Department
Allis-Chalmers Mfg. Co.

Variety of industrial steam turbines are adapted to heat-using processes and systems for generating by-product kilowatts.

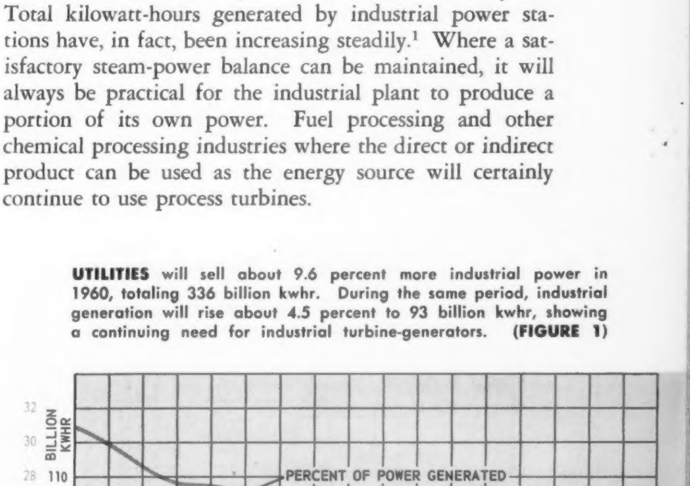
ENGINEERING STUDIES of industrial power stations usually begin with a determination of process steam requirements and electric power demands. From these known values a balance can be established that sets the most desirable steam conditions, rating and type of turbine, and boiler capacity to be applied. As a result, the initial pressure, temperature and quantity of the steam required to meet the industrial demands form the basis for selection of throttle conditions and the capability of the steam turbine-generator unit.

For economical operation the turbine-generator unit serves as a pressure-reducing valve. This arrangement permits the use of compact, efficient, high pressure boilers and results in all or most of the steam actually doing double duty. First, it gives up much of its thermal energy in the turbine for conversion to electric power. Then, at the lower pressures selected for the process, it is used for space heating, laundering, sterilization, various chemical processes or a variety of other operations.

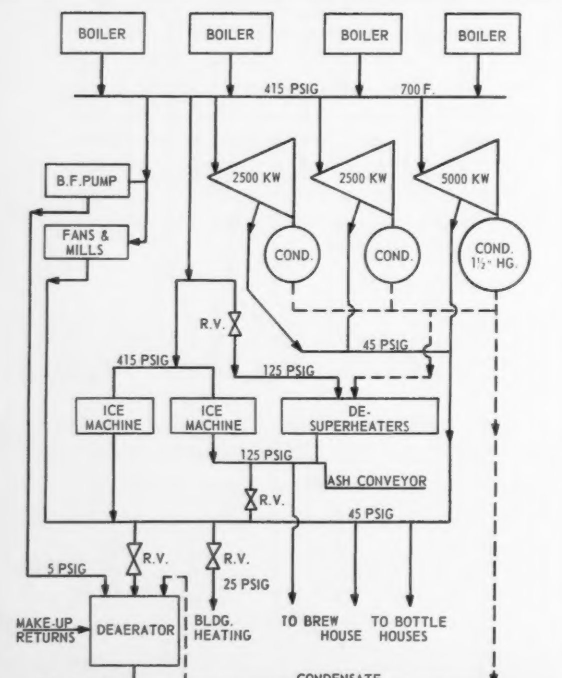
If steam exhausted from the turbine cannot be used in this manner, it must either be discharged to the atmosphere or to condensing equipment. Either method results in major heat losses and relatively low thermal efficiencies. Where exhaust steam can be used in a process, credit for its heat energy is charged to the turbine-generator unit, resulting in most efficient power production. Generally, however, the quantities of steam required by the processes are not sufficient or constant enough to permit generating all the electric power demanded by the plant. In modern industry, mechanized operations continually demand more electricity. Because electric power requirements grow more rapidly than process steam needs, industries each year purchase larger and larger percentages of their electricity from near-by utilities, as Figure 1 indicates.

The industrial turbine, however, is not on its way out. Total kilowatt-hours generated by industrial power stations have, in fact, been increasing steadily.[1] Where a satisfactory steam-power balance can be maintained, it will always be practical for the industrial plant to produce a portion of its own power. Fuel processing and other chemical processing industries where the direct or indirect product can be used as the energy source will certainly continue to use process turbines.

UTILITIES will sell about 9.6 percent more industrial power in 1960, totaling 336 billion kwhr. During the same period, industrial generation will rise about 4.5 percent to 93 billion kwhr, showing a continuing need for industrial turbine-generators. (FIGURE 1)



MILLIONS OF BARRELS OF BEER annually means vast quantities of process steam for a Milwaukee brewery. A 5000-kw condensing automatic-extraction turbine was added to supplement power generated as a by-product of the brewing process steam. **(FIGURE 2)**



STEAM EXTRACTED goes to the bottle house, brew house and heating system, while turbine exhaust steam goes to the condensers. **(FIGURE 3)**

Likewise, large hospital areas, office buildings and hotels often use such large quantities of low pressure steam for heating, cooking, sterilizing and laundering that the installation of a non-condensing turbine-generator unit can be justified because most of the steam can be trapped and recovered from the process as condensate. As a result, condensing equipment is not necessary and very little make-up water is required. Food processing firms are another major user of industrial turbines, as are large manufacturing companies and the producers of such basic metals as steel, aluminum and magnesium.

Because ratings of industrial turbine-generator units are generally determined by the plant's process demands, seldom are machines of even moderate size (by central station standards) purchased. Of 36 units recently installed, for instance, 27 were in the range of ratings from 500 kw to 10,000 kw.[2] Larger units are applied only in very special circumstances, such as the steel mill that employs a 30,000-kw unit in a topping arrangement or the utility that uses two 225,000-kw units to furnish process steam to an adjacently located refinery. Even most of these exceptional installations employ condensing automatic extraction turbines as opposed to straight condensing or non-condensing machines, so that not all of the steam is exhausted directly to the condenser.

Four basic turbine types

Turbines for industrial application are generally divided into four basic types. Depending on the process served and the amount of steam required, any type or combination of types might be installed to serve a specific industrial plant's demands. These four basic types include two broad classes of turbines: condensing machines which operate at exhaust pressures less than atmospheric; and non-condensing units with exhaust pressures greater than atmospheric. Each class is further subdivided into units having full throttle flow continuing through the turbine to the exhaust, and units in which part of the steam is automatically extracted from the turbine at some intermediate stage. A brief description of these four basic types of turbines and their applications follows:

1. *Condensing* turbines are employed where maximum power from throttle flow is desired, where condenser circulating water is readily available and where there is no need for process steam. Steam entering the turbine follows a single path through the controlling valves, the power producing nozzles and blades, and leaves the turbine exhaust end at a pressure lower than atmospheric. Higher plant cycle efficiency can be obtained through the use of extracted steam for feed-water heating.

Often straight condensing units operate in a waste heat cycle. Here, steam is generated by waste heat from any of a variety of sources. System heat losses are greatly reduced because the thermal energy is re-used in the boiler after being used in the industrial process. A typical installation is in the power station of one of the nation's largest copper producers. Here a 5000-kw condensing unit utilizes steam from boilers heated by gas from reverberatory furnaces. A similar 5000-kw machine, operating

on steam supplied from boilers using waste heat from cement kilns, is installed at a cement company in Kentucky.

2. *Non-Condensing* units are installed where exhaust steam is used for a process. They operate as reducing valves, tying high pressure boilers to systems utilizing low pressure steam. Low-cost power is generated as a by-product and at a high thermal efficiency, since the heat energy of the exhausted steam can be credited to the turbine. Non-condensing turbines usually operate in parallel with other electric power sources and can be purchased for operation with uncontrolled exhaust pressure or under back pressure control integrated with the governor. Uncontrolled operation is often regulated by a condensing automatic extraction turbine in parallel with the non-condensing machine. Typical applications are to supply large volumes of low pressure steam for industrial process plants such as paper mills, chemical plants and food processing plants.

3. *Condensing Automatic Extraction* machines are the most popular of the four basic turbine types because they combine the advantages of non-condensing and condensing units. Well over half the machines being purchased today for industrial applications are of this type. In operation, partially expanded steam is automatically extracted at an intermediate point in the turbine to supply a process and/or to regulate flow and pressure of inlet steam to a non-condensing unit operating without back pressure control. Up to the extraction point in the turbine, steam expands to process as in non-condensing machines. Beyond this stage, steam is further expanded to condenser pressure for additional power.

A typical application of this type of machine is in a power station of a large brewery, Figure 2. Here, a 5000-kw and two 2500-kw units produce a portion of the plant's electric power while serving as reducing valves to drop boiler pressure (415 psig) to a pressure (45 psig) suitable for the brewing process.[3] A flow diagram for the plant is shown in Figure 3.

4. *Non-Condensing Automatic Extraction* units are the least common of the four basic types. They are found where the advantages of a non-condensing turbine are desired for two steam pressures: high pressure from automatic extraction, and low pressure from the exhaust. Use of pressure reducing valves and desuperheaters is thereby minimized where a wide range of process pressure is desired.

A leading salt producer is using one of these turbines in his power station.[4] Steam is required at several process pressures for a variety of chemical processes, for space heating and for driving some power plant auxiliaries. The flow diagram is shown in Figure 4.

While the size and type turbine will vary with each installation, all units for operation in industrial power stations have several characteristics in common. Because they must perform in an environment where power production is not the prime reason for the plant's existence, these machines must be relatively simple in design and construction, and easy to operate and maintain. They must also be efficient and dependable.

Another characteristic of the smaller unit is the extensive use of standard and interchangeable parts. These designs minimize manufacturing, installation and maintenance costs. Machines are available with a wide variety of modifications so that the units are versatile enough to meet any process requirements. The National Electrical Manufacturers Association (NEMA) has established standards for the construction, rating and performance of steam turbine-generator units rated from 2000 to 10,000 kw, inclusive. In addition to promoting production economics, these standards assist users in the selection of generating units.

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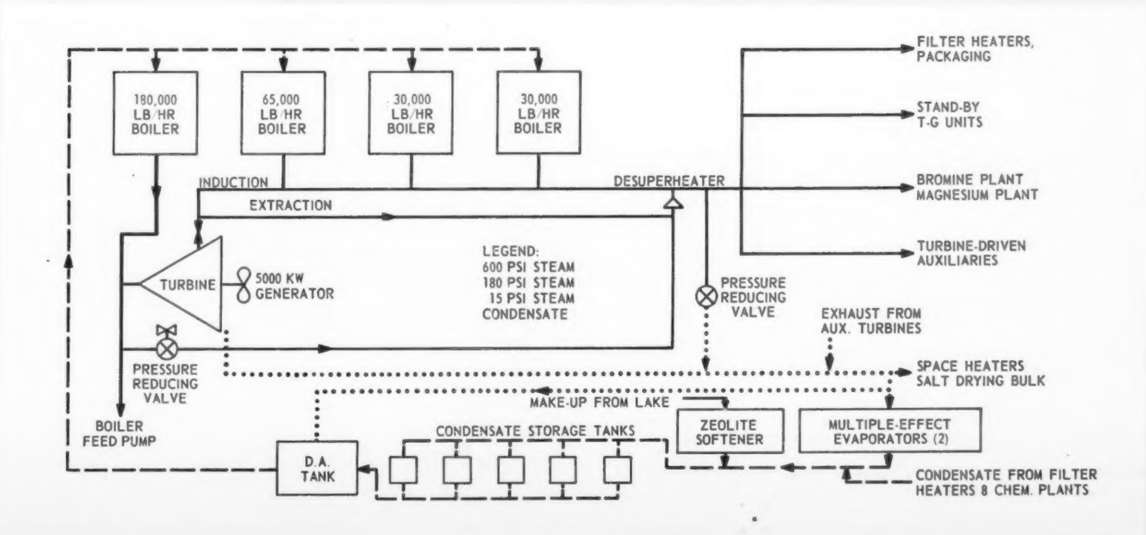
EFFICIENT, 5000-kw non-condensing turbine operates in high pressure steam plant of large salt-producing company. Steam enters turbine at 600 psig and is extracted at 180 psig for plant chemical processes. Low pressure steam at 15 psig is exhausted to bulk drying processes, space heating and vacuum pans for salt evaporation. **(FIGURE 4)**



Graphical Approach...WOUND-ROTOR MOTOR CONTROL

by **A. H. KNABLE**
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Here is a method of relating motor external secondary resistance characteristics to load requirements. The method may be used for liquid rheostat, contactor or drum-type control designs.

SINCE LARGE WOUND-ROTOR induction motors with automatic current-limiting acceleration are finding wider application for driving today's large, high inertia loads, liquid rheostats, too, are used more frequently because they provide automatic stepless control.

On the other hand, contactor or drum-type controls are more economical and quite satisfactory for the majority of wound-rotor motor applications. Since the external resistance in the rotor circuit determines the motor torque characteristic, the wound-rotor control can provide a range of motor speed or torque characteristics to satisfy a wide variety of load requirements.

The design of the secondary control requires:

1. Motor constants shown with the equivalent circuit of Figure 1.

2. The load torque-slip ($T—s$) characteristic from breakaway to final running conditions.

With the motor constants given, Figures 2, 3 and 4 can be constructed. It should be noted that in Figure 3 the working region of ($r—s—I$) can be obtained by the simple equation $I_1 = \left[(V_1/a^2)\ (s/r) + jI_0 \right]$. If it is required to cover a broader area than is normally the case, the more complete equation shown in Figure 3 must be used.

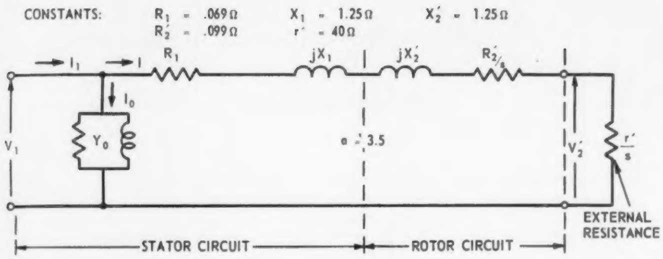
A significant relation in Figure 4 is the independence of torque and current from slip and resistance when working in a region where the ratio of slip and resistance is constant in magnitude even though slip and resistance are changing with time. This relationship exists when external resistance is employed with a wound-rotor induction motor.

Only two calculated points required

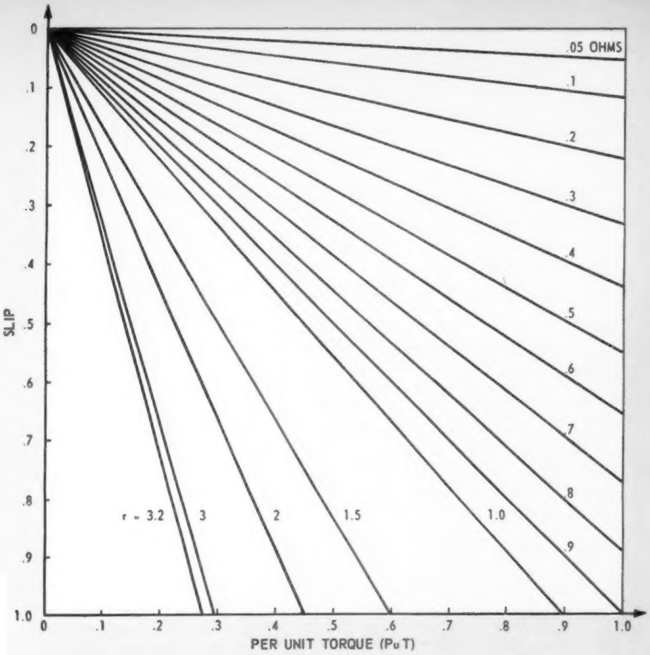
Data taken from Figures 3 and 4 can be replotted in a family of curves relating s, r, I and T as shown in Figure 5. However, Figure 5 should be constructed directly, since Figures 3 and 4 are used for explanation purposes only. The family of slip curves become straight lines when plotted on log-log paper. Only two calculations are required for the $s = 1.0$ curve to establish the slope of the family of curves. By merely noting the point of intersection of the $s = 1.0$ curve with the ordinate, the abscissa scale of Figure 5 can be used to establish the one necessary point to draw in each of the remaining slip curves. The slip curves are straight lines in the area of significance except when small values of slip, 0.1 or less, are encountered. The step-by-step calculations are performed down to a slip of 0.1, and the remaining characteristics to the running point can be sketched in with little error, as shown in Figure 8. If the problem requires more exact analysis, the more exact equations and calculations should be used throughout.

The secondary resistor characteristic shown in Figure 6 is designed into the motor secondary liquid rheostat or stepped resistor, as the case may be. Depending on the motor performance desired, the external resistor charac-

DRUM-TYPE control is used with ball mill drive. Secondary resistance is changed by steps for starting and running control.



ROTOR CIRCUIT is referred to the stator circuit using the stator-to-rotor turns ratio represented by *a*. **(FIGURE 1)**



CURVES relate *r*, *s* and *T*. *T* is proportional to *s/r* for large values of *r* and straight-line torque-slip curves result. **(FIGURE 2)**

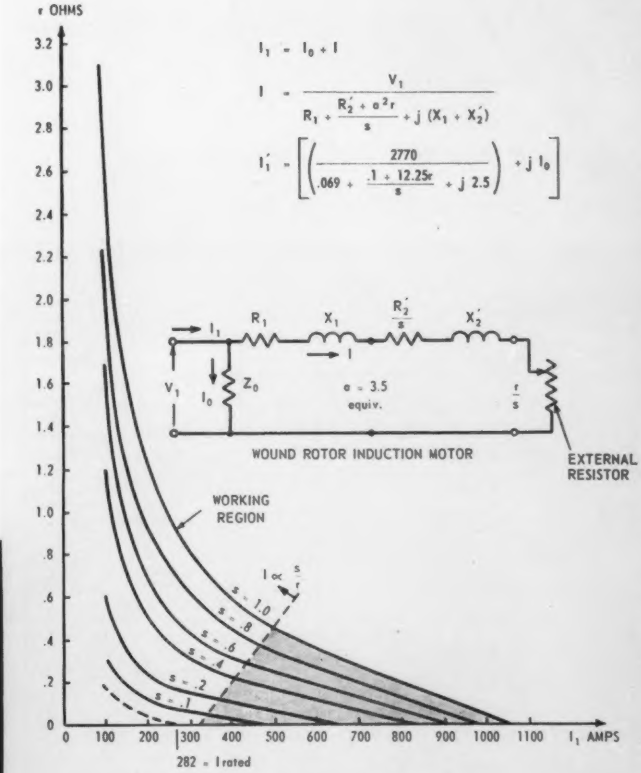
teristics will be designed to have a slow rate of change or a fast rate of change, with initial values being more or less dependent on the starting characteristics desired. The solid-line characteristic labeled "soft start" is the one used in the analyses.

The broken-line characteristic, labeled constant T and I, is shown to illustrate the characteristic that would be required if a constant torque and current at rated running value are desired.

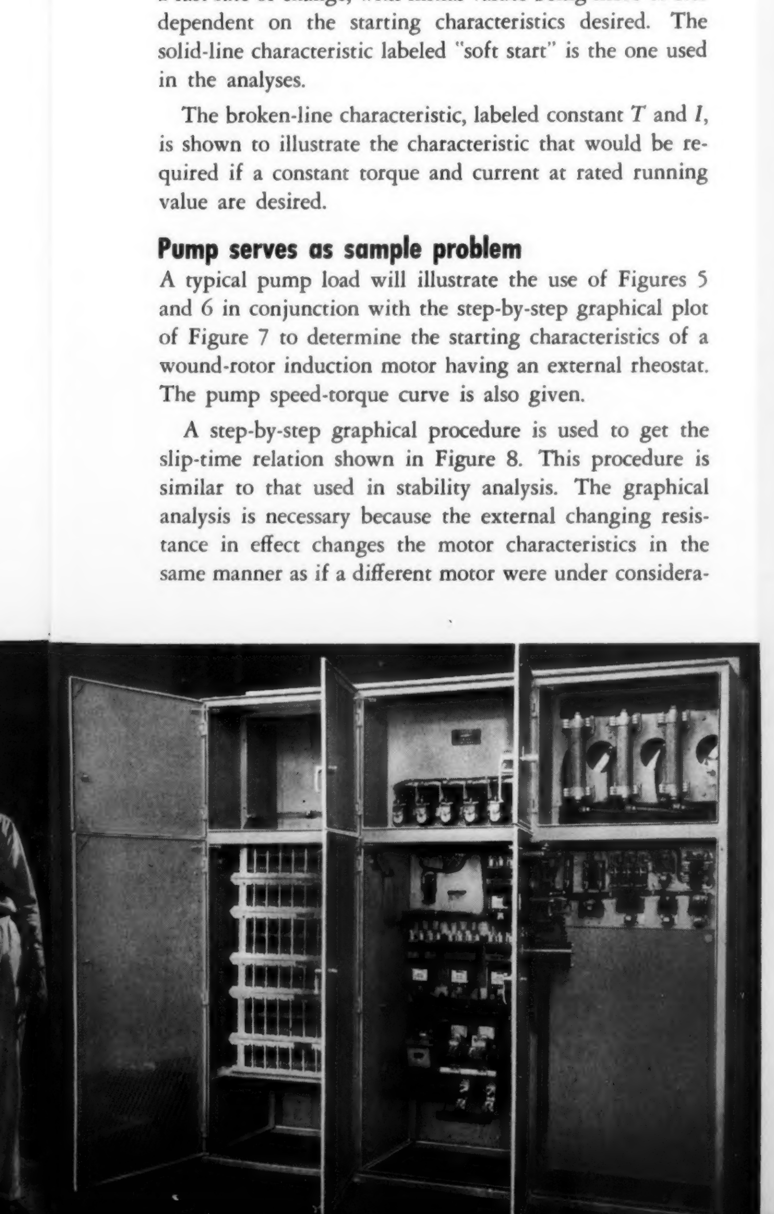
Pump serves as sample problem

A typical pump load will illustrate the use of Figures 5 and 6 in conjunction with the step-by-step graphical plot of Figure 7 to determine the starting characteristics of a wound-rotor induction motor having an external rheostat. The pump speed-torque curve is also given.

A step-by-step graphical procedure is used to get the slip-time relation shown in Figure 8. This procedure is similar to that used in stability analysis. The graphical analysis is necessary because the external changing resistance in effect changes the motor characteristics in the same manner as if a different motor were under considera-



WORKING REGION is in unshaded area where *I* is proportional to *s/r*. Curves relate values of *r*, *s* and *I* of wound-rotor motor. **(FIGURE 3)**



◀ **WOUND-ROTOR PRIMARY-SECONDARY** control changes secondary resistor steps automatically with a series of contactors.

tion every instant of starting time. The procedure is shown for points 1 and 2.

Point (1)

δ is difference between motor and load torque or accelerating torque. Two values of δ_1 are shown because of breakaway torque.

1. $\delta_1 = 0.13$ and 0.25 (left side of Fig. 7).
2. $(1/\delta_1) = 7.7$ and 4.0 — (right side of Fig. 7).
3. At $s = .95$, number of blocks $= 6$; Divide by unit area or 20 to get $t/T_a = 0.3 \therefore t = (.3 \times 3.5) = 1.05$ sec.
4. From Fig. 6 at $t = 1.05$, $r = 2.8\Omega$
5. $r = 2.8\Omega$ and $s = .95$ fixes Point (1) in Fig. 5 to yield $T = .31$.
6. In Fig. 7, $T = .31$ is projected out to $s = .90$ to establish Point (2).

Point (2)

1. $\delta_2 = .30$
2. $1/\delta_2 = 3.33$
3. At $s = .90$, number of blocks $= (3.7 + 6$ previous$) = 9.7$;

   $\dfrac{9.7}{20} = .49;\ t = .49 \times 3.5 = 1.72.$
4. From Fig. 6 at $t = 1.72$ sec., $r = 2.55\Omega$.
5. $r = 2.55\Omega$ and $s = .90$ fixes Point (2) in Fig. 5 to yield $T = .32$.
6. In Fig. 7, $T = .32$ is projected out to $s = .85$ to establish Point (3).

Point (3)

Sequence repeats until running point is reached.

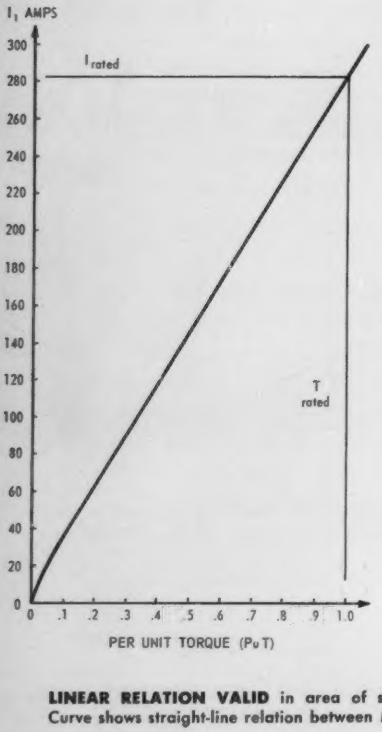
It should be noted in Figure 7 that errors in projecting to the next point tend to be self-correcting. If greater accuracy is required, smaller increments of s can be taken or other refinements in the step-by-step procedure can be made.

Figure 9, relating current and time, can then be obtained from Figures 5 and 8.

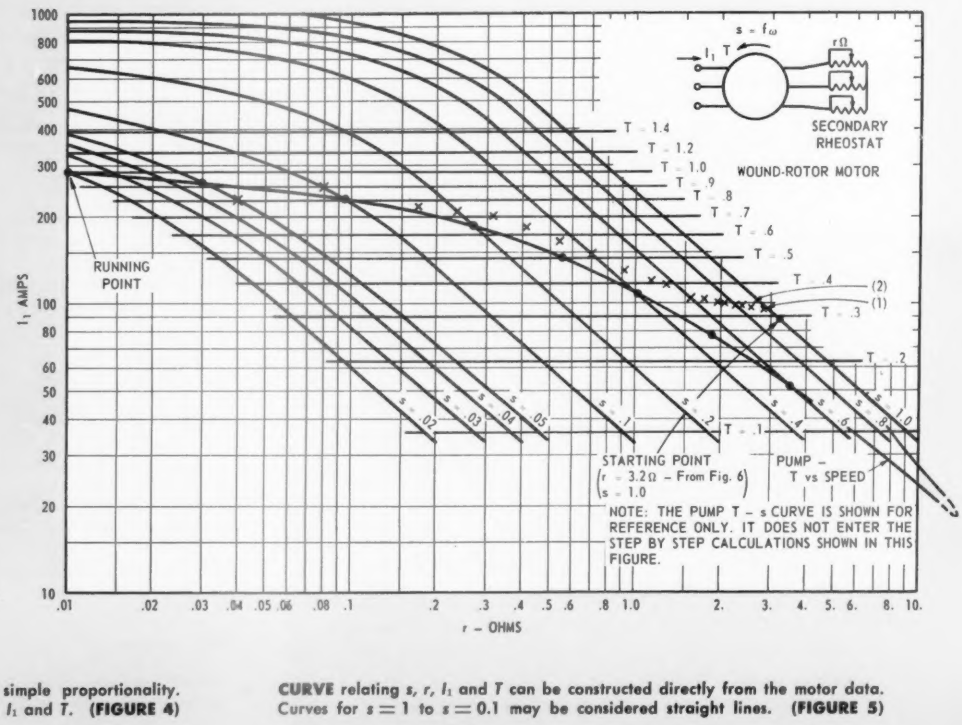
Analysis helps in motor application

Graphical analysis can be used to determine the slip-time or current-time relation for wound-rotor motors driving variable torque, constant torque or constant horsepower loads and having either stepped or rheostat-type secondary control. This analysis can be used when applying a new motor, when re-applying an older motor or changing the motor load speed-torque requirements.

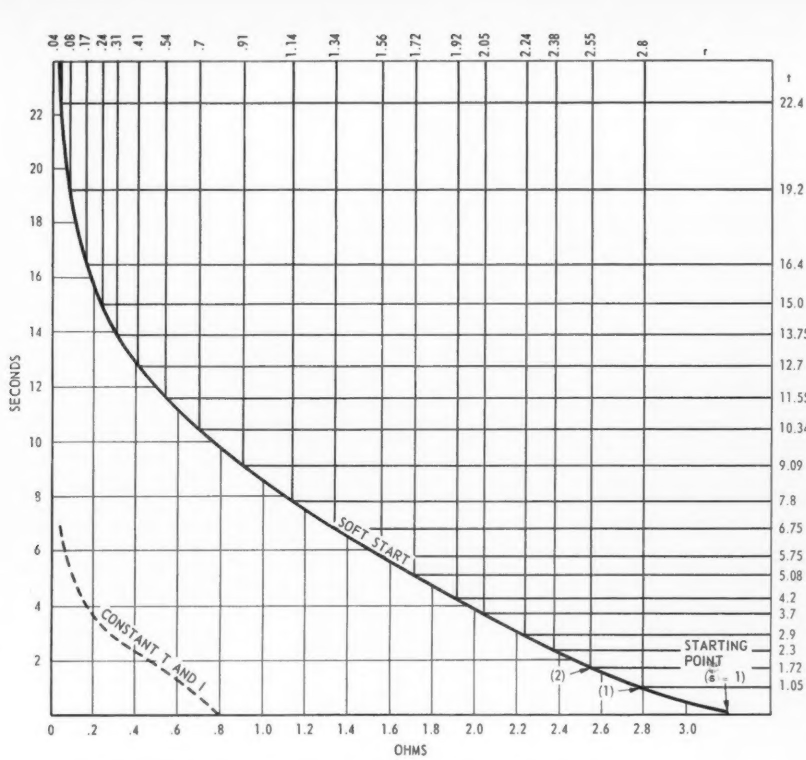
When considering any special application jobs requiring speed control or soft starting, the engineer should keep in mind the flexibility offered by wound-rotor induction motors having properly designed external rheostats.



LINEAR RELATION VALID in area of simple proportionality. Curve shows straight-line relation between I_1 and T. **(FIGURE 4)**

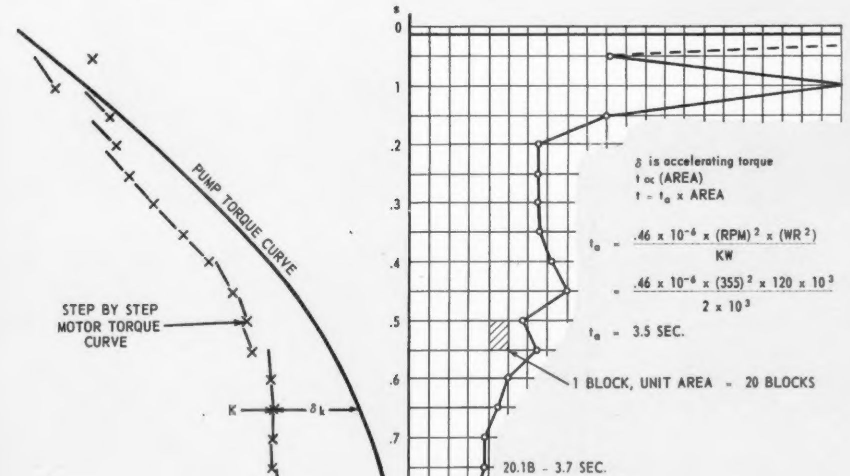


CURVE relating s, r, I_1 and T can be constructed directly from the motor data. Curves for $s = 1$ to $s = 0.1$ may be considered straight lines. **(FIGURE 5)**

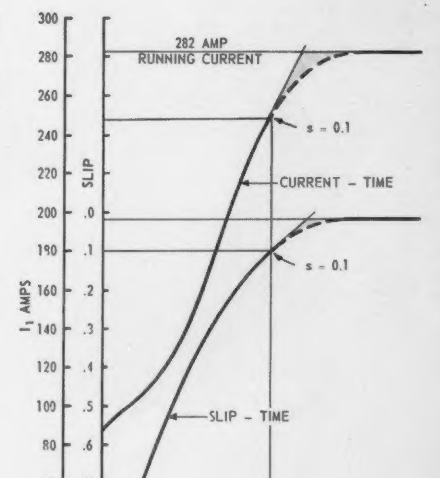


RELATION between time and liquid rheostat resistance is designed for a given type of load by changing electrode rate of travel and the shape of the movable and stationary electrodes in the rheostat. **(FIGURE 6)**

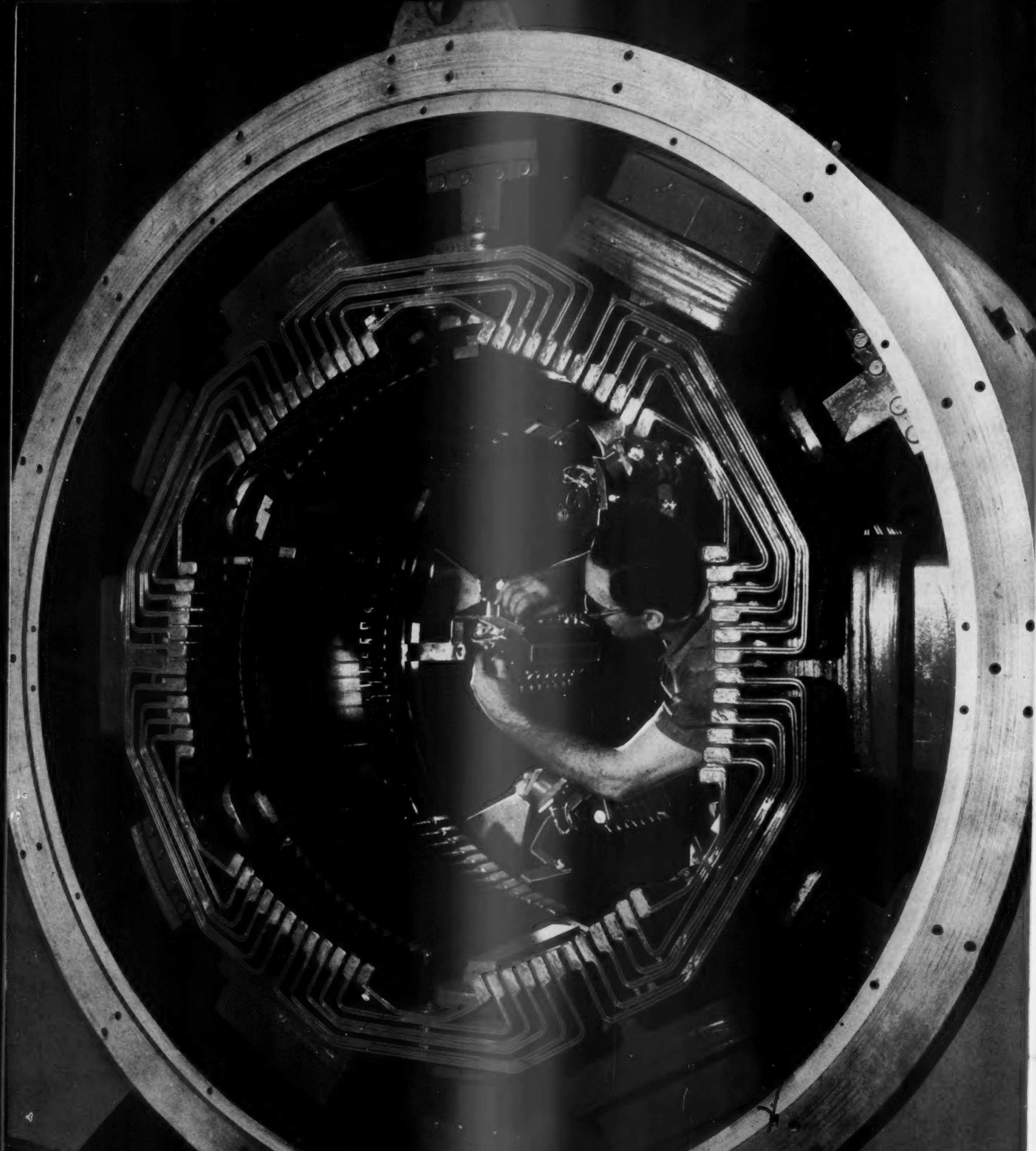
LIQUID RHEOSTATS are used to control torque, speed or current of large motors driving fans, pumps or heavy machinery. Slip of 5000-hp wound-rotor motor driving roughing mill will be controlled with this metal-enclosed rheostat.



STEP-BY-STEP graphical analysis of a wound-rotor motor with changing external resistance and a given load characteristic provides accelerating time. **(FIGURE 7)**



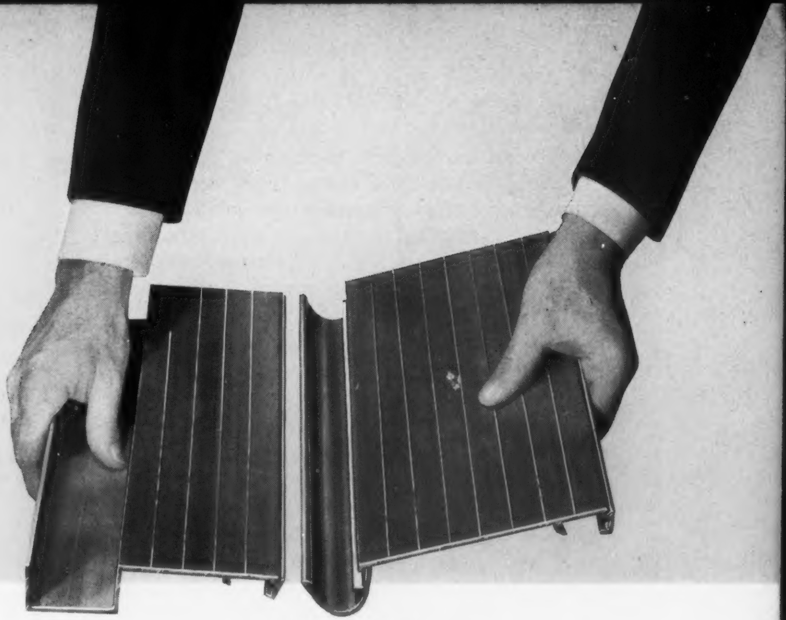
SLIP-TIME AND CURRENT-TIME curves can be readily developed from data obtained from the step-by-step analysis. **(FIGURE 8)**



COMPLETELY CAST INSULATION of main field poles and commutating poles on this 1000-kw dc generator greatly improves physical and electrical characteristics of coil assembly. The insulating structure enclosing the coils is a combination of glass fibers and epoxy-resins which keeps out contaminants and adds dimensional stability and mechanical strength. High temperature capability is another aspect of superiority. Coils are bonded together and locked to the pole by the resins. The integrated construction has been adopted as standard on stationary dc motor and generator fields as well as on rotating fields of synchronous machines.

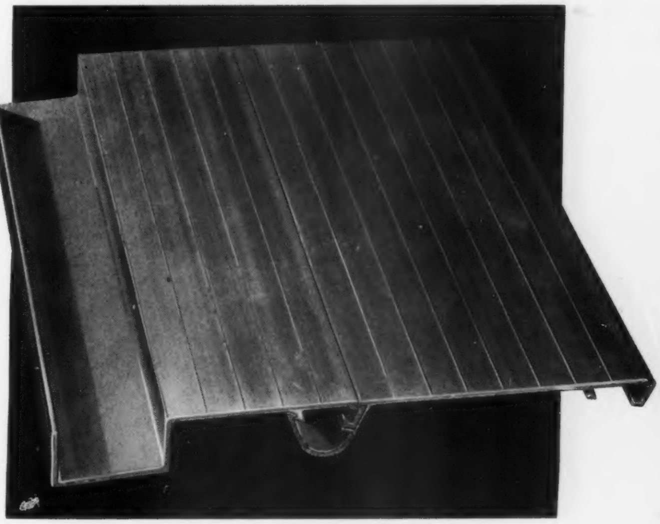
Allis-Chalmers Staff Photo by J. E. Gosseck

ALUMINUM EXTRUSIONS



...Shape New Outdoor Switchgear

by **JOHN J. DWYER, JR.**
Switchgear Department
Allis-Chalmers Mfg. Co.



SPECIALLY DESIGNED ALUMINUM EXTRUSIONS are snapped together to form a maintenance-free structure for outdoor use. Adding to the strength and rigidity of the overall structure, the snap-tight interlocking panel edges form a permanent, leakproof joint.

Extruded aluminum has solved a housing problem for outdoor switchgear. New snap-together assembly provides improved protection.

HOW CAN ALUMINUM at forty-five cents a pound compete with steel at eight cents a pound for building switchgear? This was the basic problem facing engineers when aluminum outdoor switchgear housings were first proposed. Aluminum has long been recognized as a premium material for construction of outdoor structures. It eliminates the need for paint or other protective coatings and is lighter to handle.

The advantages of aluminum were attractive for outdoor application, but past experience indicated that the disadvantages and cost would be too great to make aluminum competitive. Past experience, however, was limited to the direct substitution of aluminum into designs that had been made in steel. While aluminum alloys were known to be as strong as some steels, the low modulus of elasticity allows the aluminum to deflect about three times more than its steel counterpart under the same load. This disadvantage forced the use of larger aluminum parts to make a structure rigid, while fabrication costs for steel or aluminum were about the same. As a result, the cost of aluminum outweighed its advantages.

New concept provides answer

Aluminum extrusions introduced for fabricating aluminum structures showed considerable promise The extrusions are made by pushing metal through a die made to the shape of the section required. The result is a continuous cross section that can be cut to the desired length. By this process the section can be complex in shape without materially affecting its cost, which is slightly less than that of rolled sheet. Special sections can be designed to carry out special functions. One section used has a channel shape on one edge to provide two bolting surfaces at right angles to each other for mounting purposes.

Since there is a practical limit to extrusion sizes, a rather complex section was designed having edges that could be snapped together to form a weather-tight joint. The six-inch sections are assembled in panels by snapping sections together. A stiffening rib every six inches makes the panel more rigid than the steel panelling used for switchgear structures.

Building an outdoor housing involves more than merely putting a metal shell around the switchgear. Location can be a problem. For this reason, special care was taken in the selection of the proper alloy for all atmospheric conditions. A silicon-magnesium alloy was chosen because of its wide acceptance in the architectural field, where it has been used and tested under all kinds of conditions.

Because of load growth, switchgear substations have been placed in residential areas, where people have become conscious of substation appearance. The new type aluminum construction presents a neat appearing enclosure in which trim sections added to the housing conceal the sloping roof. These trim sections can be color anodized to set off the natural aluminum finish of the housing. To make sure that there is little reflected glare, the finish of the extrusions is left unpolished and ridges on the face of the sections break up the large surface into small vertical sections.

The advantage of reflecting solar energy in hot weather raises the question of how to dissipate the internal energy of the switchgear. To overcome this problem, the amount of convection cooling was increased and more area allowed for the filter air inlets and outlets.

The extrusion processes for aluminum have made possible an attractive, lightweight, strong housing in which standard indoor switchgear can be operated and maintained without interference from the weather.

▲

LIGHTWEIGHT ALUMINUM rear panel section of the switchgear housing is easily removed by one man without the use of a crane. Each cubicle is bolted on and can be inspected individually. Strength of the assembled aluminum sections is about equal to that of one-half inch steel plate.

ATTRACTIVE ALUMINUM SWITCHGEAR housing eliminates the need for primers, enamels, sealers, and periodic repaintings to protect it from weather wear. The 80-inch service aisle within the weatherproof housing provides a smooth surface on which to roll high voltage breakers for inspection.

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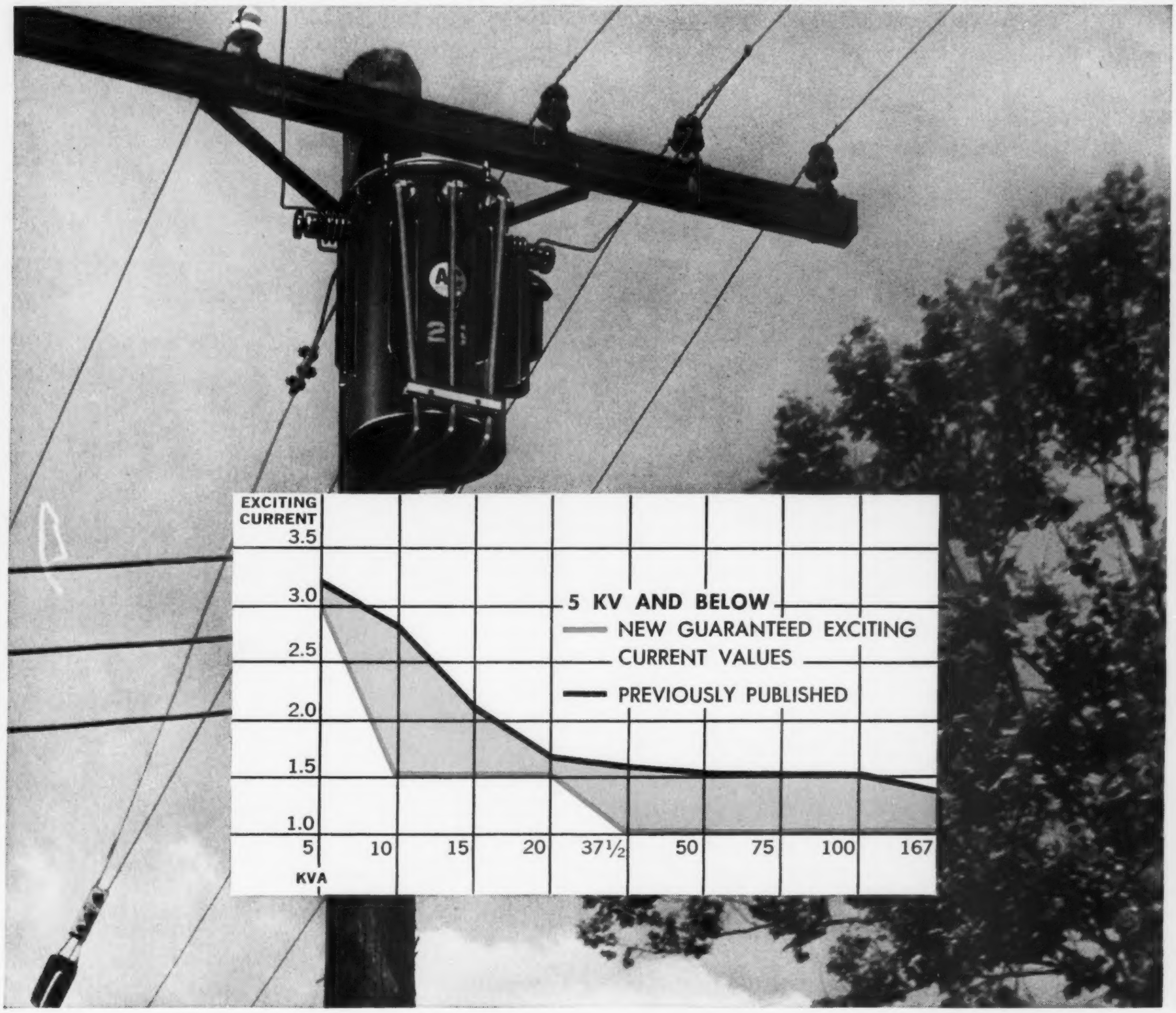

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Research and Development

Provide Data for Pump-Turbine

PUMPED-STORAGE hydroelectric project economics usually dictates very large size pump-turbines. Studies are now in progress which will involve ratings of over 250,000 horsepower as a pump, and the output of a comparable amount of power as a turbine. Since units of this size are far beyond the range of factory test facilities, homologous models must be used to provide needed design information.

While the model is relatively large, the actual pump-turbine may be as much as 14 times larger in linear dimension. This difference in size between the model and the large machine places a premium on the precision of the model manufacture and the model test work. A good example of the importance of accuracy is the determination of the torque required to turn the wicket gates. This torque is called the wicket gate moment. The wicket gate moment in the model shown amounts to slightly less than 7 foot-pounds per gate. The equivalent wicket gate moment in a pump-turbine of 200,000 horsepower size would be in the neighborhood of 100,000 foot-pounds. An error of 5 percent in the model reading would amount to an error of approximately ⅓ foot-pound and would not appreciably alter the mechanical design of a machine the size of the model. However, a like percentage error in the large unit would be equivalent to 5000 foot-pounds.

In these tests the wicket gate lever is used as a calibrated spring, and a small strain gage accurately measures gate deflection. Through the calibration of the wicket gate lever, the deflection can be translated into a moment. Each wicket gate lever is strain-gaged to monitor the maximum wicket gate moment under all operating conditions. This broad surveillance makes it possible to establish a true maximum wicket gate moment.

Despite the precision that has been necessary in the development of all the components of these massive units, the work has been well justified by the more than a million horsepower of pumped-storage units in operation, being built or immediately contemplated in the United States alone.

by **WILTON W. WELTMER**
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